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INVERSE FEED-BACK

by B. D. H. TELLEGEN.

Summary. In this article the influence of inverse feed-back on the properties of an amplifier is examined. After a discussion of the decrease of the non-linear distortion by inverse feed-back, the stability of an inverse feed-back amplifier is studied. In addition it is shown that the influence on the amplification by changes in the supply voltages or in the characteristics of the receiving valve can be decreased by inverse feed-back, and that the internal resistance of an amplifier can be either increased or decreased by inverse feed-back.

Principle of inverse feed-back

If part of the output voltage of an amplifier is fed back to the input, many properties of the amplifier will be modified. If the amplification is increased, we speak of direct feed-back, if on the other hand it is reduced we speak of inverse feed-back. This latter was investigated in 1928 in this laboratory by K. Posthumus [1]) and in the Bell Laboratories by H. S. Black [2]).

Several properties of inverse feed-back have been described previously in this periodical [3]). We propose in the present article to submit it to a closer investigation.

If inverse feed-back is applied to an amplifier, as shown in *fig. 1*, we must distinguish between the signal voltage E_s and the input voltage E_i of the amplifier itself. The difference between these two is the inverse feed-back voltage E_t. If the voltages are calculated as positive when they act in the directions indicated by the arrows, the following holds:

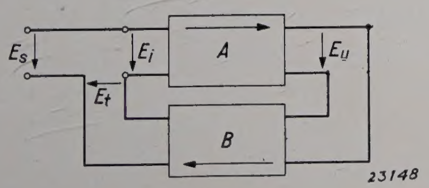

Fig. 1. Diagram of inverse feed-back, A amplifier, B inverse feed-back circuit. A portion E_t of the output voltage E_u is led back to the input side of the amplifier.

$$E_i = E_s - E_t \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Influence on the amplification and on the distortion

In order to calculate the change in amplification caused by inverse feed-back, we imagine a sinusoidal signal voltage of a definite frequency to be applied. Then, if α is the amplification without inverse feed-back and β is the portion of the output voltage E_u which is employed for inverse feed-back:

$$E_u = \alpha E_i,$$
$$E_t = \beta E_u, \text{ and therefore}$$
$$E_t = \alpha \beta E_i.$$

If this is substituted in (1) it gives:

$$E_i = \frac{1}{1+\alpha\beta} E_s \text{ and therefore}$$

$$E_u = \frac{\alpha}{1+\alpha\beta} E_s \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$E_u = \alpha E_i$ will in general differ from E_i, not only in size, but also in phase, and the same is true of the feed-back voltage $E_t = \alpha \beta E_i$. The factors α and $\alpha\beta$ are therefore not pure numbers, but quantities which include a phase angle, and which are represented in the vectorial notation of alternating current theory by complex numbers.

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[1]) K. Posthumus, Brit. Pat. 323823.
[2]) H. S. Black, Stabilized feed-back amplifiers, Bell System techn. Journal **13**, 1 (1934), published also in El. Eng. **53**, 114 (1934).
[3]) C. J. van Loon, Philips techn. Rev. **1**, 264, 1936.

If $\alpha\beta$ is real and positive, the amplification is decreased. If $\alpha\beta$ is real, negative and less than one in absolute value, the amplification is increased and we are concerned with direct feed-back. If $\alpha\beta = -1$, the amplification becomes infinite, that is to say, the system is no longer stable. In this case it is in fact possible for an undamped sinusoidal oscillation to be maintained in the system without a signal, because the fact that $\alpha\beta = -1$ means that at a given amplitude E_u the feed-back voltage E_t has just the magnitude and phase necessary to create an input voltage which generates E_u again. If $\alpha\beta$ is real, negative and greater than one in absolute value, one might think that the system is always unstable. Closer examination of the stability, to which we shall return later, has however shown that this is not necessarily always the case. In general, if the system is stable, it is the absolute value $|1 + \alpha\beta|$ which determines the change in amplification. When this absolute value is large with respect to one, $1 + \alpha\beta$ approaches $\alpha\beta$ and (2) is simplified to

$$E_u = \frac{1}{\beta} E_s \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

From this we see that the quantity α no longer occurs in (3). Now α, the value of the amplification without feed-back, will in general be a function of the frequency, to which it is not always easy to give the desired form, and moreover α depends upon the characteristics of the valves, in particular on their slopes, which may vary because of several causes. All valves of the same type have not exactly the same slope, and the slope varies to a certain extent during the life of the valves, and also depends upon the voltage of the mains or of the batteries, which is not always constant. When a strong inverse feed-back is applied, the amplification depends only on β which is determined by the inverse feed-back circuit. In general this circuit will include no valves and may more easily be constructed in such a way that β will depend on the frequency in the desired relation. To what degree the amplification depends less upon variations in α when inverse feed-back is applied, than without inverse feed-back, may be given simply for the case when $\alpha\beta$ is real, that is, when the inverse feed-back is accurately in phase. In order to determine the corresponding percentage change in $\dfrac{\alpha}{1+\alpha\beta}$ at a definite percentage change in α, we must calculate the quantity

$$\frac{\mathrm{d}\dfrac{\alpha}{1+\alpha\beta} : \dfrac{\alpha}{1+\alpha\beta}}{\mathrm{d}\alpha : \alpha}$$

which is found to be $\dfrac{1}{1+\alpha\beta}$ that is equal to the decrease is amplification.

Equation (3) suggests another advantage of inverse feed-back. An amplifier is in general not entirely linear, due to curvatures of the valve characteristics, and therefore harmonic and beat frequencies may appear in it. The inverse feed-back circuit may consist of linear elements, it may therefore be expected that, when the amplification depends on β alone, no harmonic or combination frequencies will appear in the output voltage E_u.

The fact that this assumption is correct, and to what degree the harmonics are suppressed was shown in a previous article in this periodical [4]). In the following the calculation of the influence on the second harmonic by inverse feed-back will be repeated in a somewhat more general form, which is not subject to the limitations mentioned in footnote (4). We assume that the signal voltage E_s is truly sinusoidal. If there is a second harmonic of a certain amount P present in the output voltage, there will be an amount of second harmonic βP present in the inverse feed-back voltage. Since the signal itself contains no second harmonics, according to (1) the input voltage will contain an amount $-\beta P$ of second harmonics. This amount $-\beta P$ leads to an amount $-\alpha\beta P$ of second harmonics at the output of the amplifier. Moreover, an amount Q of second harmonics is generated in the amplifier by the non-linear elements in it. In the case of small distortion Q depends only on the strength of the fundamental frequency in the input voltage, and is not influenced by the amount $-\beta P$ of second harmonics present. Thus Q is the amount of second harmonics in the output voltage of the amplifier when no inverse feed-back is applied, and when a sinusoidal signal voltage of such a size is applied that the fundamental component of the output voltage is just as large as in the case just considered with inverse feed-back. Since we began with an amount P of second harmonics in the output voltage, we arrive at:

$$P = -\alpha\beta P + Q,$$

Therefore

$$P = \frac{Q}{1+\alpha\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

It follows from the derivation that α and β in

[4]) C. J. van Loon, loc. cit. In this article the influence of inverse feed-back on the second and third harmonics is calculated.The derivation is limited to the case where α and β are real and independent of the frequency.

(4) must be taken at the frequency of the second harmonic, and not at the fundamental frequency. The amplitude of the second harmonic, therefore, at a given output voltage is decreased due to inverse feed-back by the same factor as is the amplification of a signal having the frequency of that harmonic. When the distortion becomes larger, and higher harmonics appear, the relations are no longer so simple [5]), but the fact remains true that the distortion at a given output voltage is decreased by strong inverse feed-back.

If a interference originates in the amplifier, due for instance to mains supply, then it may be shown in an analogous way to that used above for the second harmonic, that this is decreased in the output voltage of the amplifier by means of inverse feed-back in the same ratio, as is the amplification of a signal having the frequency of the disturbance.

Stability

The considerations which led to equation (2) have as a basis the tacit assumption that the inverse feed-back system is stable. In order to determine this fact we must examine the manner in which the system will continue to oscillate if it is left to itself after the application of a slight disturbance, that is to say, we must examine the free oscillations of the system. If these are all damped, the system is stable; if one or more of the free oscillations grows with time, the system is unstable. The borderline between these two conditions is that condition when one of the free oscillations is an undamped sinusoidal oscillation. As has already been shown, this limiting case will exist when $\alpha\beta = -1$. We may now determine $\alpha\beta$ by measurement or calculation as to magnitude and phase as a function of the frequency, and plot $\alpha\beta$ as radius vector for each frequency. The length r of the radius (see *figs. 2* and *3*) thus indicates the relation between the voltage E_t fed back and the input voltage E_i. The angle φ gives the amount by which the phase of E_t is in advance of that of E_i. The connecting line from the end points of the vectors which correspond to different frequencies will form a curve, which we call the vector diagram of the inverse feed-back, and which will usually be closed, since $\alpha\beta$ is generally zero not only for the frequency zero, but also for the frequency ∞. If the amplifier consists for instance of a single stage of resistance amplification in which a constant portion of the output voltage is employed for inverse feed-back (fig. 2), then C_1 is generally so large, and C_2 so small, that they have no in-

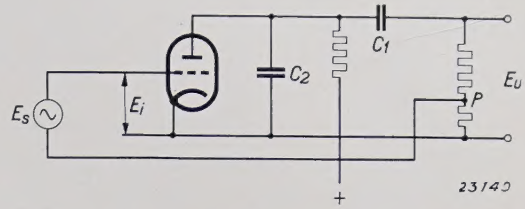

Fig. 2. Resistance amplifier with inverse feed-back. The voltage taken off at point P is in phase with E_i for average values of the frequency; for low frequencies the phase is 90° in advance, for high frequencies 90° behind.

fluence on the amplification over a large part of the frequency range to be amplified. In this range therefore $\alpha\beta$ is practically constant, and has a small phase shift, which changes very slowly with the frequency. At the lowest frequencies the amplification will however decrease because of the presence of C_1, and at the highest frequencies due to C_2. This change in amplification is accompanied by a phase change of the amplification, which is 90° at the frequencies zero and infinity. This has as result that the vector diagram of $\alpha\beta$ has about the form of a circle (*fig. 3*).

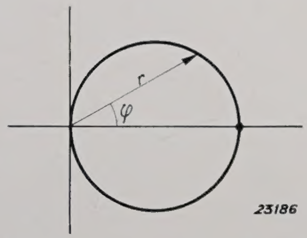

Fig. 3. Vector diagram of one-stage resistance amplification (Fig. 2) with inverse feed-back. The phase changes from 90° ahead at low frequency to 90° behind at high frequency.

If the amplifier consists of two stages of resistance amplification in cascade arrangement, in which a constant portion of the output is used for inverse feed-back, then the phase change of the amplification for the frequencies zero and infinity will be 180°, and we obtain a vector diagram of the form given in *fig. 4*. If the amplifier or the inverse feed-

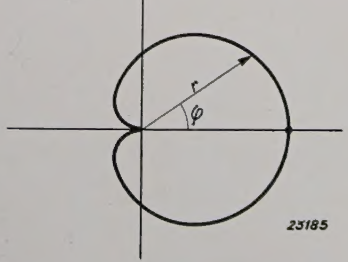

Fig. 4. Vector diagram of two-stage resistance amplification with inverse feed-back. The phase changes twice as fast as with one stage. Thus from 180° ahead to 180° behind.

[5]) R. Feldtkeller, Die 3te Teilschwingung in Verstärkern mit Gegenkopplung, Telegr. und Fernsprechtechn. **25**, 217, 1936.

back circuit contains resonances, $\alpha\beta$ may be very much changed in the neighbourhood of those resonance frequencies as regards magnitude and phase, so that vector diagrams of complicated forms may occur.

In order to investigate the stability for all cases, we assume that we gradually increase the inverse feed-back from zero to the desired value, that is, that we substitute $n\beta$ for β, where n is a positive number independent of the frequency, which we allow to increase starting from zero. The vector diagram will then change congruently with itself. If n is small, the vector diagram is also small, and the point —1 on the real axis lies outside the diagram. The system will always be stable for small values of n, and we desire to know what happens to the stability when n increases from zero. We mentioned already that on the threshold of instability, one of the free oscillations has become an undamped sinusoidal oscillation. If this is the case, $\alpha\beta$ will equal —1. At the transition from stable to labile the vector diagram therefore passes through the point —1 on the real axis. Upon increase of n the system will thus remain stable as long as the point —1 on the real axis lies outside the vector diagram. If this point falls within the diagram, the system becomes labile. It may however happen that upon further increase of n the vector diagram passes the point —1 on the real axis for the second time. Then there are two possible cases: either the free oscillation which had been increasing with the time is again damped and the system therefore again stable, or a second free oscillation begins to increase instead of being damped and the system remains labile. Nyquist [6]) has shown that these cases may be distinguished by the forms of the vector diagrams. If the diagram has the form of *fig. 5a* for example, then the system upon increase of n is first stable, then labile and finally stable again. In this last state therefore we have a system for which $\alpha\beta$ is, for two frequencies, real, negative and of an absolute value greater than 1, while the system is still stable. If however the diagram has the form of fig. 5*b* for example, then the system upon increase of n changes from stable to labile, while it remains further labile. This result was formulated as follows by Nyquist: if the point —1 on the real axis lies outside the vector diagram, the system is stable, if the point lies within the vector diagram the system is labile.

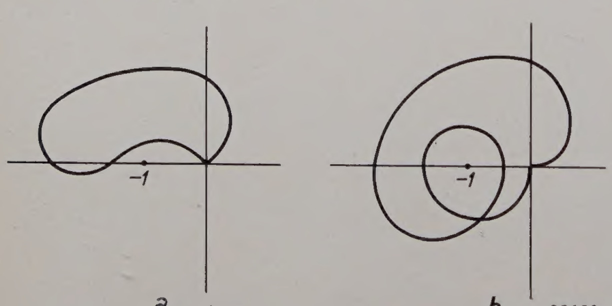

Fig. 5. *a*. Vector diagram of a stable system which upon decrease of the inverse feed-back becomes labile. *b*. Vector diagram of a labile system which remains labile upon increase of the inverse feed-back.
A system is stable when the point — 1 lies outside the closed curve of the vector diagram; labile when this point is within the curve.

[6]) H. Nyquist, Regeneration Theory, Bell Syst. Techn. Journal, **11**, 126 (1932).

Voltage and current inverse feed-back

Up to now we have not spoken of the loading resistance of the amplifier, and have considered this as a part of the amplifier. If we desire however to investigate the behaviour of the inverse feed-back amplifier when the loading resistance Z_u is variable, we must consider it separately from the amplifiers. We can then distinguish two cases. Either the ratio between the inverse feed-back voltage E_t and the output voltage E_u, which we have called β above, is independent of Z_u, or the ratio between E_t and the output current I_u, which we shall call γ, is independent of Z_u. Since $E_u = I_a Z_u$, the relation $\beta = \gamma/Z_u$ exists between β and γ. In the first case we speak of voltage inverse feed-back, in the second of current inverse feed-back. These two cases are represented in *figs. 6a* and *b*. If Z_u is made smaller, in case *a* the output voltage E_u (due to the internal resistance of the amplifier) will decrease, and the same holds

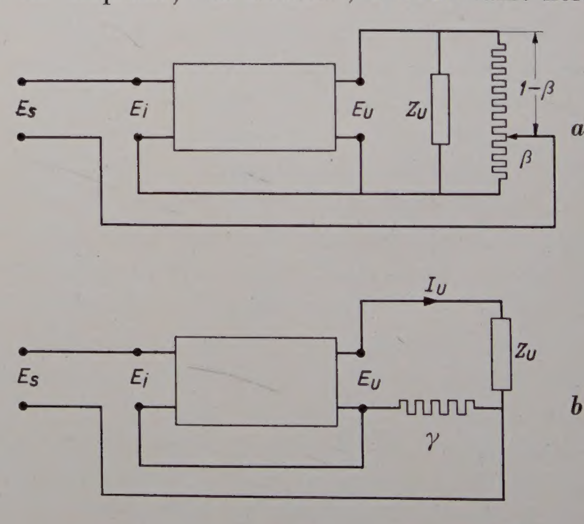

Fig. 6. *a*. Voltage inverse feed-back. The ratio between the inverse feed-back voltage and E_u is independent of Z_u.
b. Current inverse feed-back. The ratio between the inverse feed-back current and I_u is independent of Z_u.

for the inverse feed-back voltage βE_u. In case *b* on the other hand, upon decrease of Z_u the output current I_u will become larger, and consequently also the inverse feed-back voltage γI_u.

We saw above that with strong inverse feed-back the amplification approaches $1/\beta$, that it depends therefore only slightly upon Z_u with voltage inverse feed-back, and that with current increase feed-back it is about proportional to Z_u, or in other words that the internal resistance becomes small with voltage inverse feed-back, while the internal resistance becomes large with current inverse feed-back.

We should like to examine this change of internal resistance more closely. Every linear system which ends in a pair of terminals, as regards its external effects, may be replaced by its open-circuit voltage with its internal resistance connected in series. We shall apply this theorem to an amplifier for the calculation of the internal resistance. If an input voltage E_i acts on the amplifier, then the open circuit voltage at the output end may be represented by vE_i, and the internal resistance by Z_i. If the amplifier is loaded with a resistance Z_u we arrive at the arrangement

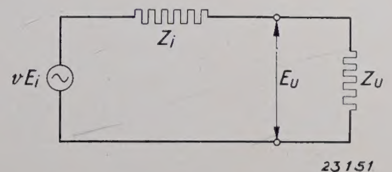

Fig. 7. Equivalent circuit of an amplifier with input voltage E_i, no-load voltage $v\,E_i$, internal resistance Z_i and external resistance Z_u.

of *fig.* 7. The voltage on Z_u is thus,

$$E_u = v E_i \cdot \frac{Z_u}{Z_i + Z_u} \quad \cdots\cdots \quad (5)$$

and the amplification a is thus given by:

$$a = \frac{v Z_u}{Z_i + Z_u} \quad \cdots\cdots\cdots \quad (6)$$

When inverse feed-back is applied, we saw above (eq. (2)), that the relation between E_u and E^s is given by:

$$E_u = \frac{a}{1 + a\beta} E_s \,.$$

Substituting in this the value of a from (6):

$$E_u = \frac{v Z_u}{Z_i + Z_u + v\beta Z_u} E_s \quad \cdot \cdot \quad (7)$$

If we are concerned with v o l t a g e inverse feed-back, β is independent of Z_u, and we write (7) in the form:

$$E_u = \frac{v E_s}{1 + v\beta} \cdot \frac{Z_u}{\dfrac{Z_i}{1 + v\beta} + Z_u} \quad \cdot \quad (8)$$

If we compare (8) with (5), we see that, due to voltage inverse feed-back, the internal resistance is changed to

$$\frac{Z_i}{1 + v\beta} \,.$$

At the same time we see that the open circuit voltage is changed to

$$\frac{v E_s}{1 + v\beta}$$

The stronger the voltage inverse feed-back, the smaller the internal resistance becomes. If Z_u, Z_i, a, β and v are all real and positive, it follows from (6) that a is smaller than v, so that the internal resistance diminishes more than the amplification due to the voltage inverse feed-back, since the latter decreases from a to $a/(1 + a\beta)$. If however the internal resistance without inverse feed-back is already small with respect to the external resistance, then a and v are about equal, and, with voltage inverse feed-back, amplification and internal resistance are about equally diminished.

If we are concerned with c u r r e n t inverse feed-back, we substitute γ/Z_u for β in (7), since γ is now independent of Z_u and then obtain:

$$E_u = v E_s \cdot \frac{Z_u}{Z_i + v\gamma + Z_u} \quad \cdot \cdot \quad (9)$$

Comparing (9) with (5) we see that, due to current inverse feed-back, the internal resistance is changed to

$$Z_i + v\gamma \,.$$

The stronger the current inverse feed-back, the larger the internal resistance becomes. If Z_u, Z_i, a, γ and v are all real and positive, it follows from (6) that a is smaller than $v\,Z_u/Z_i$. Now the internal resistance increases by the factor

$$\left(1 + \frac{v Z_u}{Z_i} \cdot \gamma/Z_u\right),$$

while the amplification decreases by the factor

$$(1 + a \cdot \gamma/Z_u),$$

as appears from equation (2) upon substitution of β by γ/Z_u. From this it thus follows that the internal resistance increases more strongly due to current inverse feed-back than the amplification decreases. If however the internal resistance without inverse feed-back is already large with respect to the external resistance, then a is about equal to $v\,Z_u/Z_i$, and with current inverse feed-back

the internal resistance is increased by the same amount as the amplification is decreased.

By the application of a combination of current and voltage inverse feed-back, at a given degree of inverse feed-back, any desired internal resistance may be obtained.

We have seen from the above that by the application of inverse feed-back many characteristics of an amplifier may be influenced in a simple way, and other properties may be improved to an important degree. The one disadvantage is a loss in amplification. Due to the improvement of amplifier valves, however, it is now possible to get a high amplification with a small number of valves, so that this loss of amplification in many cases need no longer be considered a great disadvantage when compared with the advantages attained. Inverse feed-back has been used recently, not only in telephone amplifiers [7]), where, because of the large number of amplifiers connected in cascade arrangement, a great constancy of the amplification is necessary, while in carrier wave telephony, intermodulation is prevented at the same time, but also in radio receiving apparatus and amplifiers for sound reproduction [8]), in which the decrease in distortion and the simple way of modifying the frequency characteristic are of great advantage.

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[7]) W. Six and H. Mulders, The use of amplifiers in telephone technique, Philips techn. Rev. **2**, 209 (1937).

[8]) B. D. H. Tellegen en V. Cohen Henriquez. Inverse feed-back, its application to receivers and amplifiers. Wirel. Eng. **14**, 409, 1937.

THE APPLICATION OF MAGNETIC OIL FILTERS TO LUBRICATING SYSTEMS

by L. H. DE LANGEN.

Summary. An apparatus is described which can remove small magnetic particles from an oil-stream. The decrease in wear on shafts and the like obtained with this apparatus is discussed.

After the lubrication of bearings and other parts of machinery had been the exclusive concern of the engineer for many years, this domain of technology was brought within the reach of science about the end of the last century. The problem was at first attacked chiefly from the mathematical point of view. In setting up the hydrodynamic lubrication theory [1]) Reynolds began with the proportionality between the sliding stress appearing in the lubricant and the fall in velocity. Sommerfeld, Michell, Gümbel and others later developed the theory further. Of the various assumptions which form the basis of the hydrodynamic lubrication theory the following two are of importance for our subject:

1) that the surfaces which slide over each other are quite smooth and
2) that the lubricant is a pure liquid.

In practice neither of these two conditions is entirely fulfilled. Recent investigations have shown that most surfaces, as obtained in the workshop by the usual means, even when they are observed under moderate magnification, resemble a mountain landscape. The heights of the mountains in this landscape are of about the same order of magnitude as the thickness of the lubricating oil layer. It is therefore not surprising that when these surfaces are allowed to slide over each other the theory of lubrication is scarcely applicable; the oil film is broken, and considerable wear occurs.

The writer has ascertained on various occasions that even with highly-finished bushes in which a shaft had run for several hours, the diameter had become several hundredths of a millimetre greater; the tops of the mountains had been worn away. Because of this wear the second assumption, namely that the lubrication is carried out with a pure liquid, is no longer justified. The particles of metal worn off circulate with the liquid and cause further wear. This experience leads to the statement of the following paradox: a bearing must be lubricated with as small an amount of oil as possible. When the oil is contaminated due to wear it is actually better to use little oil, so that only a few solid particles take part in the further wear and tear of the surfaces. Of two approximately equally loaded bearings of a certain construction, one of which received very much oil and the other, because of accidental circumstances, almost nothing from the same oil reservoir, the first showed by far the greater wear.

With the above in mind it is not difficult to indicate methods for improving lubrication and decreasing wear and tear. In the first place more ideal surfaces must be aimed at, and in the second place methods must be found of removing the metal particles carried by the oil before they cause further wear.

It is now possible, even in ordinary production, by making use of modern methods of treatment such as lapping and honing [2]) to give the surfaces of shafts and bearings such a finish that the above-mentioned first condition is fairly well satisfied.

This article will describe a method developed in this laboratory of continually removing the particles of iron from the oil, so that the second condition may also be fulfilled. This method is as follows: the circulating lubricating oil flows continuously through a strong magnetic field, so that the iron particles are attracted to one of the poles and separated from the oil.

The latest development of magnet steel has made it possible, with permanent magnets of moderate dimensions, to attain fields of such strength that even very small iron particles can be taken out in this way.

Fundamentally the magnetic oil filters consist of a cylindrical permanent magnet placed in a cylindrical space enclosed by iron walls. A simple

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1) O. Reynolds. Phil. Trans. Roy. Soc. London **177**, 157 (1886).

2) Lapping is a method of polishing in which a metal surface is polished with another softer metal surface, with the addition of an abrasive suspended in a liquid. By giving the correct form to the polishing surface it is possible in this way, not only to make the parts smooth, but also true in shape and dimensions. Honing is a similar process, in which however stone is used for the polishing surface instead of a fine abrasive embedded in a soft metal. The finished surface is somewhat less smooth.

construction is drawn in *fig. 1*. The permanent magnet A is placed in a steel tube B. Three brass wires C soldered to the magnet hold it in the middle

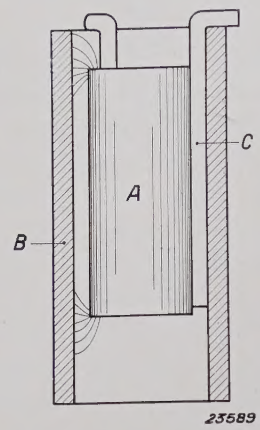


Fig. 1. Simple magnetic oil filter.

of the tube. The lines of force of the magnet are drawn in the left-hand half. If oil contaminated with particles of iron flows through this tube, the iron is deposited mainly on the upper side of the magnet at the points of highest concentration of magnetic flux, as may be seen in the photograph (*fig. 2*) of a contaminated magnet.

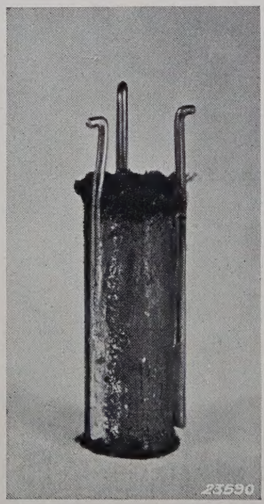


Fig. 2. Magnet with iron filings.

An oil filter of this construction is very satisfactory, but is somewhat limited in capacity; because the impurities are deposited as a narrow ring, the filter is quickly full.

An oil filter of more perfect construction is shown in *fig. 3*. The permanent magnet A is fastened to an iron cap B, which is screwed into the iron housing C. A brass cylinder D with holes E is placed around the magnet in order to direct the oil which enters at F and leaves at G. This construction has three important advantages. Firstly a good magnetic circuit is formed here with only one air gap so that with a given length of the permanent magnet

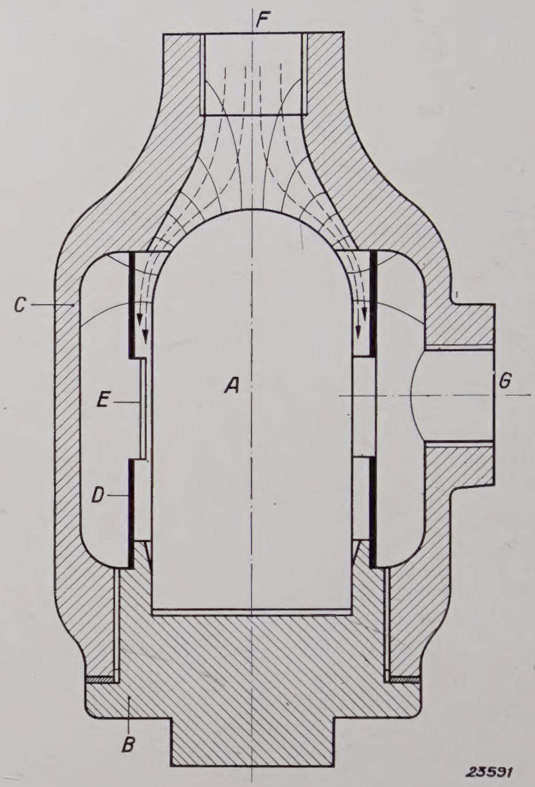


Fig. 3. Cross section of an oil filter. The magnetic lines of force are indicated by continuous lines and the stream lines are dotted.

the strongest possible field is generated. Secondly the convex pole of the magnet is so placed with respect to the housing that the particles of iron are deposited over the whole convex surface, and the filter can therefore collect a large amount of impurities. Thirdly the air gap is of such a form that the oil entering flows in about the same direction as that in which the iron particles are attracted. The lines of force and the stream lines cross each other at small angles; therefore the iron particles are subject to the attractive effect of the magnet over a long distance.

Various magnetic filters have been employed in the Philips organisation for some time. The first general application is to be found in the film projectors of the Cinema Department, which are now equipped with magnetic oil filters. Successful attempts have been made along two lines to limit the wear and tear on film projectors. The first step was that of making the surfaces of the parts truer and smoother. A great deal has been achieved in this respect. All shafts and bearing bushes are lapped or honed, the Maltese cross also is finished by a special lapping treatment to give great

smoothness and high precision (tolerances 1 to 2 microns). The toothed wheels, however, have an ordinary finish, which is obtained by hobbing with a fine milling cutter. Grinding or lapping of these little toothed wheels is not yet possible. During working the toothed wheels produced iron dust which, acting as an abrasive, spoiled the smooth surfaces of the lapped shafts, the Maltese cross etc. In this case the use of simple magnetic filters effected a great improvement. Two of these filters are built into the housing of the Maltese cross. *Fig.* 4 is a cross section through one of these filters.

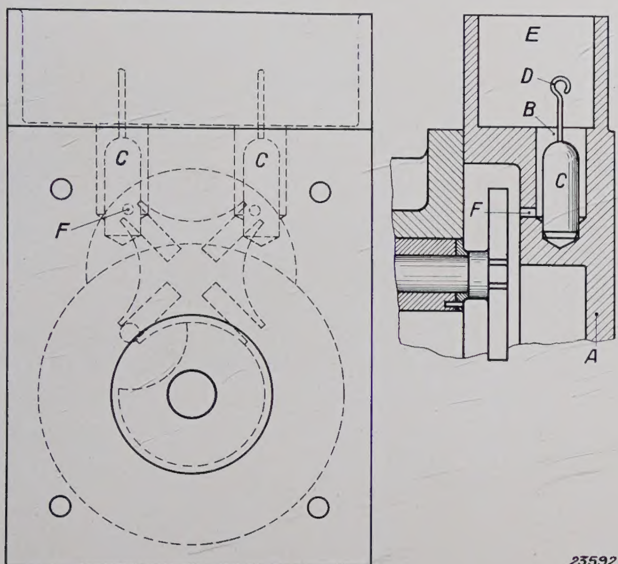


Fig. 4 The oil filters. *C* are here introduced into holes *B* in the housing *A* of the Maltese cross of a film projector. In the front view (left) they are dotted, and to the right is a cross section through a magnet.

A is a part of the housing, *B* is a hole in which the permanent magnet *C* is placed. *D* is a wire of non-magnetic material which is cast in. *E* is an oil reservoir which is continually refilled by the oil pump. The oil flows through the hole *F* into the housing. Of the oil passing through the pumps only that portion is filtered which is intended for the Maltese cross. Since, however, the circulation is rapid, the whole of the oil eventually finds its way through the filter to the Maltese cross. This method is very satisfactory; if a magnetic filter is introduced into a projector whose oil has become dark-coloured from the ground-off iron particles, the oil may be seen to become clear again after a little time. The length of the captured particles of iron seems to lie between 0.4 and 4 microns. The grinding off decreased rapidly after the initial working in, as may be seen from the graph of *fig.* 5.

Especially in the case of the Maltese cross is the limitation of the wear and tear extremely important; a Maltese cross in which there is play due to wear begins to knock harder and then wears off even more rapidly.

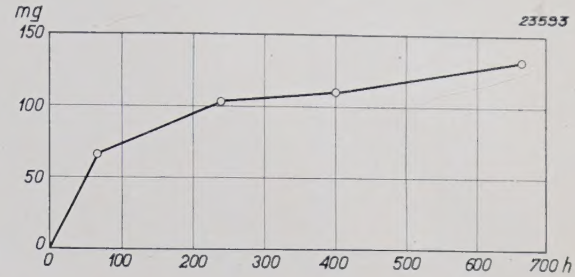


Fig. 5. Wear and tear on a projector: weight of the iron particles deposited by the magnetic oil filter as a function of the number of hours during which the projector had run.

We have also introduced a magnetic filter into an overhauled automobile motor, whose cylinders had been honed and whose pistons had been provided with new piston rings. A filter like the one in fig. 3 was placed in the pressure oil system in such a way that all the oil passed through it. After the car had run 500 km the filter contained 673 mg of iron particles whose size varied between 0.4 and 5 microns. *Fig. 6* is a photograph of the magnet after it was taken out of the filter housing. Later on the wear became less, as may be seen from the graph of *fig.* 7. The graph representing the wear and tear has the same form as that found in the case of the cinema projectors.

Fig. 6. Oil filter magnet covered with iron filings.

Magnetic oil filters also have been used with success in various industrial machines. In the

isolated case of an oil filter introduced into the lubricating system of a steam turbine, which had been running for some time, only a small amount of worn-off metal was found, as would be expected.

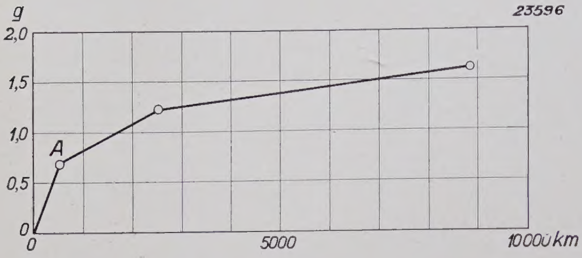


Fig. 7. Wear and tear on an overhauled automobile motor: weight of the iron particles deposited on the oil filter as a function of the distance the car had run. The magnet of fig. 6. was taken out of the filter housing at the moment represented in this figure by the point *A*.

In the employment of magnetic oil filters there are various methods to be followed. In the case of machines which are not too large it is best to introduce an oil filter into the main feedpipe of the pressure system. With larger machines having a large amount of circulating oil it may be sufficient to pass only a portion of the oil flow through the filter by installing it in a branch pipe of the supply. Another possibility is the introduction of a simple oil filter directly before each lubrication. In many cases it is not difficult to arrange the holes for the lubricant in such a way that a magnet can be introduced, for example in the way done in fig. 4.

With a magnetic oil filter of course only magnetic particles can be captured; particles of bronze or white metal thus remain in the oil. Fortunately the parts which are most subject to initial wear and tear are as a rule made of iron or steel, such as gear wheels, piston rings, cylinders etc.

In many cases where bronze is now often employed, cast iron may be used to advantage. Thus for example the use of cast iron bearings in the Philips projector was a success, and as an additional advantage any particles from the bearings were captured in the magnetic filter.

The wear due to metal particles in the lubricating oil has also been investigated by means of the following simple test. A silver steel shaft lapped as in normal production, 10 mm in diameter, ran for $1^1/_2$ hours in smooth bronze bearings. In order to be sure that the lubrication would not be unfavourably affected be too tight a fit the play was arranged to be large namely 0.06 mm (difference of the diameters). The shaft, which made about 1000 revolutions per minute, was driven by a belt of string; the tension of the string was the only load on the shaft. The bearings were lubricated with oil which had been artificially contaminated with iron particles taken from the magnetic oil filter of a projector. After the conclusion of this test the shaft showed ringshaped grooves visible to the naked eye. With a special Busch microscope for the examination of surfaces, a photograph was made of the worn part of the shaft and of a portion which lay outside the bearings. This photograph is shown in *fig. 8*. Two objects

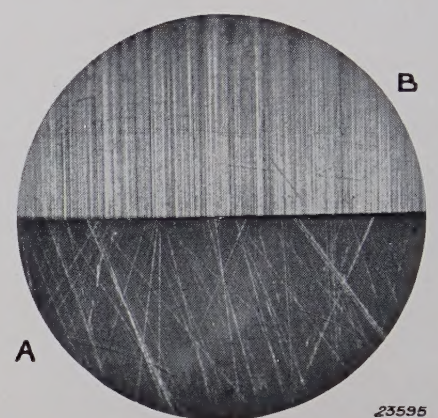


Fig. 8. Photomicrograph of the surface of a shaft with illumination from one side. *A* is the new and *B* the worn portion. Magnification 102 diameters.

which are illuminated obliquily may be placed under the microscope for comparison of the surfaces. If the surfaces are completely smooth the light is reflected to the other side; the perpendicularly placed microscope receives no light. If there are grooves or inequalities in the surface, light is also reflected in a vertical direction. Looking through the microscope, light streaks or points may be observed. Part *A* of the photograph shows the undamaged portion of the shaft. The fine criss-cross scratches of the polishing treatment may be clearly seen. It is not difficult to produce a much more perfect surface which appears practically black in the microscope, but for ordinary purposes this extreme quality is not necessary.

Part *B* is a picture of the worn shaft. Nothing can be seen of the original polishing scratches; instead there are now the much coarser grooves due to wear. By means of this simple test which can easily be repeated it is shown convincingly that attention must be devoted to meaures for the purification of circulating lubricating oil.

Tests will be carried out on a still larger scale on the application of magnetic oil filters. We hope to announce the results of such tests in the future.

A DECIMETRE WAVE RADIO LINK BETWEEN EINDHOVEN AND NIMEGUEN

by C. G. A. VON LINDERN and G. DE VRIES.

Summary. A radio connection between Eindhoven and Nimeguen is described in which use is made of waves of about 25 cm length. Magnetron transmitters and superheterodyne receivers are employed. Directional aerials in the shape of paraboloids of revolution are used, having an amplification factor of about 20.

Introduction

Transmitting valves for waves of about 25 cm (1200 Mc/s) have recently been considerably improved, so that they are able to generate relatively high powers. This fact led us to make use of these waves in an experimental connection between Eindhoven and Nimeguen. The terminals of this link were about 50 km apart and set up on the 50 m tower of the lamp factory in Eindhoven and on a water tower situated on one of the highest points in the neighbourhood of Nimeguen. In a previous article the writers have already indicated the most important condition for satisfactory transmission: a free optical path. The free path is in this case of even greater importance owing to the shorter wave lengths used.

Fig. 1 shows how the path from Eindhoven—Nimeguen is situated with respect to sea-level. The line of direct sight is the line joining the transmitting aerial on the tower of the lamp factory with the aerial on the water tower. It may be seen from the figure that, just as in the case of the Eindhoven—Tilburg beam, the line of direct sight is always at least 10 m above the treetops and any buildings.

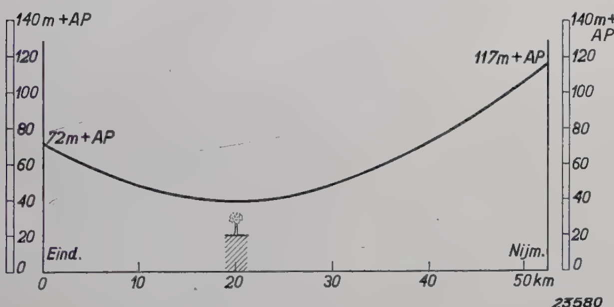


Fig. 1. The curved line represents the line of direct sight between transmitter and receiver in the link between Eindhoven and Nijmegen. The earth is drawn flat there as x-axis; this represents sea level in the Netherlands.

Transmitting tests in the direction of Nimeguen carried out with the aid of an experimental rotating Yagi aerial, which is shown in fig. 5 p. 302 of our previous article in this periodical, confirmed the fact that there was a free optical path, since the field strength received in Nimeguen corresponded with what would be expected, given a free path, to the same order of magnitude.

The aerial

In order to obtain some idea of the dependence of the received strength on the frequency used, one may in the first place consider the case in which transmitter and receiver are set up free from the earth. If transmitter and receiver are both free in space and far removed from the earth, the field strength at the receiving end is proportional to the square root of the energy W in the dipole of the transmitter and inversely proportional to the distance R between transmitter and receiver, thus equal to $k_1\sqrt{W}/R$.

While with 1 m waves we used Yagi directional aerials, with 25 cm waves the paraboloid of revolution must be considered. The directing action of these mirrors is appreciably greater; at a diameter of 3 m it is about six times as great as that of the previously described Yagi directional aerials whose amplification is about 3.5. The amplification of such a reflector is roughly equal to $\frac{\pi R'}{\lambda}$, where R' is the longest radius of the paraboloid and λ is the wave length, both expressed in the same unit [2]).

It is obvious that such an amplification is due to the small angle of divergence in the polar diagram of the paraboloid; this diagram is indeed much more satisfactory than that of the Yagi aerial. As may be seen from *fig. 2* the angle of divergence is about 11°. For secrecy, in the sense of desiring to communicate with only a definite region, this is an advantage.

If paraboloids are used for transmitting and receiving aerials with radii R_1' and R_2' respectively and amplification factors g_1 and g_2 respectively, the field strength becomes proportional to:

$$g_1\, g_2\, \frac{\sqrt{W}}{R} \text{ or } \frac{\pi R_1'}{\lambda} \cdot \frac{\pi R_2'}{\lambda} \cdot \frac{\sqrt{W}}{R}\,.$$

This field strength is however not important, it is

[1]) Philips techn. Rev. 1 (1937).

[2]) C. J. H. A. Staal, Transmitt. News 3, No. 3 (1936).

rather the induced electromotive force in the aerial which is important. The receiving aerial is half a wave length long, so that the included electromotive force is proportional to $g_1 g_2 \lambda \frac{\sqrt{W}}{R}$ or to $\frac{R_1' R_2'}{\lambda R} \sqrt{W}$. We therefore see that the signal which reaches the receiver increases proportionally with the frequency, when the diameters of the paraboloids

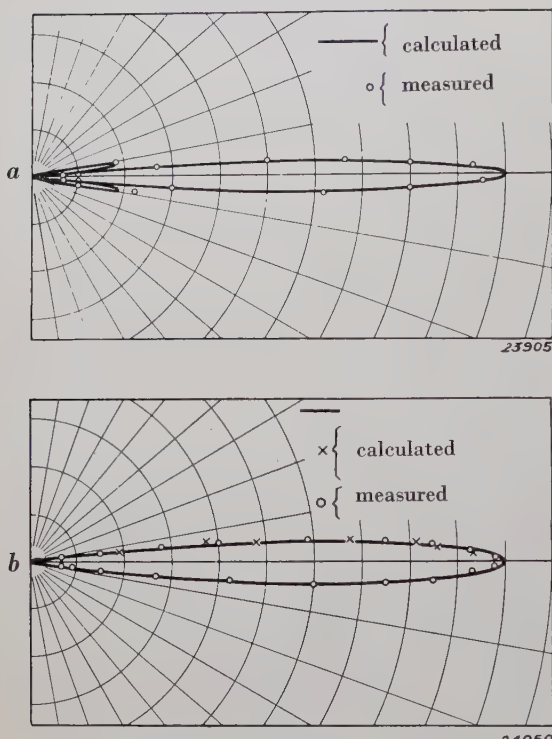


Fig. 2*a*) Horizontal, *b*) vertical polar diagrams measured and calculated for a paraboloid of revolution with a vertical dipole at the focus.

and the transmitting energy are kept constant. In addition the conditions for waves of 25 and 125 cm may be compared with each other with the aid of these expressions. If the diameter of the paraboloid at the transmitting end is 3 m and at the receiving end 1 m, and if the transmitting energy is 5 watts, then, at the wave length used, the electromotive force induced in the receiving aerial is larger than in the 125 cm wave connection Eindhoven—Tilburg, where two Yagi aerials are used, and the energy at the transmitting end is calculated to be 10 watts. The transmission on the shorter wave is possibly more favourable than on the longer wave, considering that the line of direct vision is a greater number of wave lengths from the earth. Moreover the final result depends not only upon the EMF induced in the aerial, but equally upon the sensitivity of the receiver used.

The magnetron transmitter

When a relatively large amount of energy must be produced at a frequency of 1200 Mc/s (wave length 25 cm) the most suitable energy source is at present a magnetron. In general a magnetron is a diode with a cylindrical anode in one or more sections, and an electron emitting filament which is placed approximately along the axis of the cylinder. A constant magnetic field is applied in the direction of the filament. The paths of the electrons are thus curved, since the strength of the electric field E acting on the electron and the centrifugal force $m v^2/r$ are directed toward the outside, while the Lorentz force $e v H$ due to the magnetic field is perpendicular to the path and toward the inside (*fig. 3*). The latter

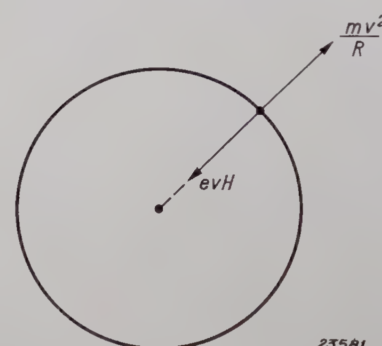


Fig. 3*a*. Forces acting on an electron in a homogeneous magnetic field when no electric field is present, but when the electron has a definite initial velocity.

component is proportional to the velocity of the electrons and the strength of the magnetic field. In the absence of an electric field the electrons move along a circular path whose radius depends upon the velocity of the electron. When a radial electric field is present, the path will be practically

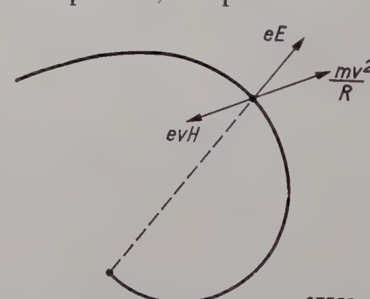


Fig. 3*b*. Forces acting on an electron in a magnetic field when a radial electric field is present.

heart-shaped. With a suitable anode voltage and magnetic field this electron motion leads to a negative resistance between the segments of the anode within a certain frequency range, so that it is possible to use the magnetron as an oscillator. If the negative resistance is greater than the ohmic resistance of the LC circuit of the tuned double wire feeder

(Lecher system) connected with the magnetron, any oscillation present increases in amplitude until an equilibrium state is reached at a greater amplitude due to the curvature of the characteristic. This holds of course for every oscillator circuit.

The problems which present themselves when a magnetron is to be employed for the purpose of communication include among others the question of modulation, and of the reliability of the wireless connection. Modulation of the anode voltage offers various difficulties. The frequency of a magnetron oscillator changes appreciably with the anode voltage, while in addition the characteristic which represents the high-frequency voltage as a function of the anode voltage is not only not straight, but exhibits discontinuities [3]). In order to have a steady signal strength, the energy sources must deliver a constant voltage. A constant magnetic field can easily be realized by the employment of a permanent magnet as shown in *fig. 4*. When

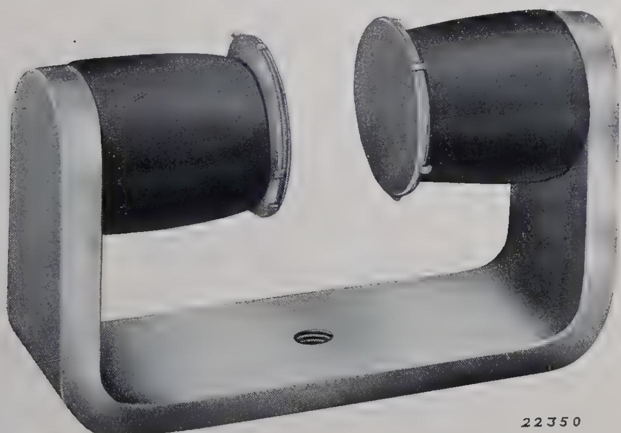


Fig. 4. A permanent magnetic for a magnetron for a wave length of 25 cm. The field has a strength of 1000 gauss.

this is done there is not only the great advantage of the unvarying frequency, but also the fact that one need not be concerned with the supply to an electromagnet and the smoothing of the direct current voltage necessary for that purpose. In addition to a saving in weight in the installation, this means an improvement in efficiency of the whole outfit. Another point is the question of the permissible variation in the anode voltage. This quantity depends upon the receivers used, as will be shown later, and may not be more than 0.1 volt. Thus the variation must be less than 0.1 per cent. This is achieved by means of a special voltage regulator based upon the following principle: a portion of the voltage which is to be kept constant is compared with a constant dry battery; any deviation of the voltage varies a resistance which is included between the source of the voltage and the transmitter. It is the principle of the inverse feed-back direct current amplifier. The filament current also must remain strictly constant. This can be achieved with the aid of a hydrogen-filled iron wire resistance lamp.

We have employed a special *system of modulation*, which was constructed for magnetron transmitters but is in general applicable for the modulation of oscillators whose frequency depends to a large degree upon the voltage to be modulated. The method of modulation comes to this, that *the amplitude* of the carrier wave is *not changed*, *but the time* during which the transmitter oscillates. When no low-frequency modulation voltages are applied to the transmitter, the oscillator is allowed to generate periodically in such a way that the period during wich it is generating is equal to the period during which it is not generating. The low-frequency modulation voltages cause a change in the ratio of these periods, in the sense that when the generating period is lengthened, the period in which no oscillations occur is equally shortened, and *vice versa*. The result is that the average high-frequency energy for each moment of the low-frequency period will correspond with the instantaneous amplitude of the low-frequency alternating current voltage when the interruption frequency is large with respect to the low frequency. This will in the end produce the same result in the receiver as if the aerial energy varied in the more usual manner. The attractive feature of the method is that neither the dependence of the anode voltage nor the disadvantage of the non-linear and discontinuous modulation characteristic plays the slightest part, although it must immediately be added that a disadvantage of the method lies in the fact that the range of frequencies transmitted is limited to about 20 000 c/s. for practical reasons which will be mentioned later.

The periodic oscillation and non-oscillation can be brought about in different ways. One of the methods which we used and which is employed in the installation described consists in the following. A variable resistance is introduced in parallel with the magnetron, and the magnetron (and therefore also the resistance in parallel with it) is fed through a constant resistance. If the variable resistance is infinite, the magnetron works normally; if the variable resistance is made smaller, it begins to take some current and the voltage over the common resistance will therefore change, and with this the voltage of the magnetron also. There are now two

[3]) C. G. A. von Lindern, Transmitt. News **2**, No. 2 (195).

courses open: in the first place one may make the current consumption of the variable resistance so large that the magnetron ceases to generate, for which

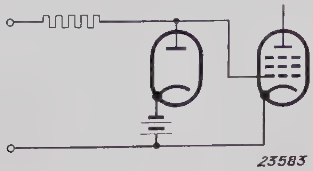


Fig. 5. The diode with series resistance to limit the voltages in the grid circuit of the pentode.

purpose the anode voltage need not be greatly changed. In the second place one may make the current consumption of the variable resistance smaller so that, while a large variation in frequency occurs, the oscillation is not interrupted. In the latter case therefore two waves are radiated so that the reliability of a connection is in general improved. It will depend further upon the receiving system used which method is chosen, since the two wave lengths lie relatively close to each other, and the result might be that with a less selective receiver one would hear nothing at all of the modulation. We have however chosen the latter method since a sufficiently selective superheterodyne receiver was being used, and moreover because a slight variation in current makes the transmission of the lower register easier, due to the fact that then the smoothing condenser of the high voltage feeder may be smaller. For the variable resistance we used a pentode, the first grid of which we made periodically highly negative "cut off" and then less negative. We achieved this by means of a saw-tooth alternating voltage whose amplitude was large with respect to the necessary variation in the grid voltage of the pentode. When this grid voltage is about zero (the saw-tooth voltage has the extreme values of $+A$ and $-A$) the change over takes place from infinite resistance to a smallei resistance. The way in which that resistance becomes constant after the change, and how at the same time the grid of the pentode is protected from overload will be explained later. At present the important fact is that the change takes place in a short interval of time; it must of course take place during a small part of the period of the saw-tooth voltage whose frequency is large with respect to that of the low-frequency voltages. It is therefore possible to cause this change to take place at any moment of a period of the saw-tooth voltage by introducing a direct voltage in series with the saw-tooth voltage. When this direct voltage is $+A$, the variable voltage will never be infinite in other words, the magnetron will no longer generate, while, when the direct voltage is $-A$, the generating of the magnetron will be uninterrupted.

If instead of a direct voltage we introduce in series with the saw-tooth voltage an alternating voltage whose frequency is small with respect to the auxiliary frequency, the magnetron will also generate when the alternating voltage is negative, and will not generate when the alternating voltage is positive. One may therefore modulate the magnetron transmitter in this way. When the amplitude of the low-frequency alternating voltage is A, that is,

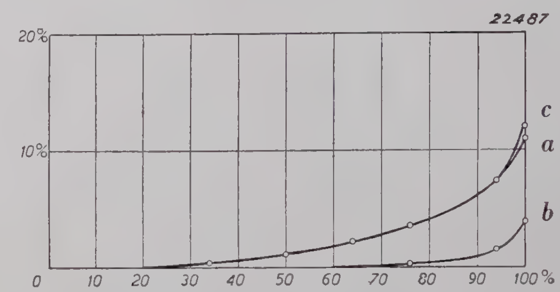


Fig. 6. The distortion as a function of the depth of modulation when a sinusoidal auxiliary voltage instead of a sawtooth voltage is employed.

equal to that of the saw-tooth voltage, the depth of modulation is 100 per cent. In any case of course when the low-frequency alternating voltage has the maximum amplitude A the depth of modulation is at a maximum.

In order to provide that immediately after the pentode has attained the correct resistance this state will be maintained during the rest of the saw-tooth period which is making the pentode grid more positive, a diode is introduced between the grid and the filament of the pentode, as shown in *fig. 5*. The diode has a very small internal resistance and the series resistance is of such dimensions that it is large with respect to the internal resistance of the diode. Thus when the anode of the diode is just slightly positive with respect to the cathode, the saw-tooth voltage will be taken up by the series resistance, and a practically constant voltage between the grid and the filament of the pentode remains. It is therefore clear that the grid of the pentode is protected against overloading, but also that the relaxation times in the grid circuit, which are determined by resistance and capacity, (and this holds also for the anode circuit) begin to play a part. This is the reason why the frequency band to be transmitted is limited to about 20 000 cycles per sec. A simplification of the installation is possible by the use of a sinusoidal auxiliary voltage instead of a saw-tooth voltage. *Fig. 6* shows the distortion

caused thereby as a function of the depth of modulation. It may be seen that this distortion is not serious.

Figs. 7, 8 and *9* are photographs of the transmitter installation used, of the magnetron and of the parabolic reflector.

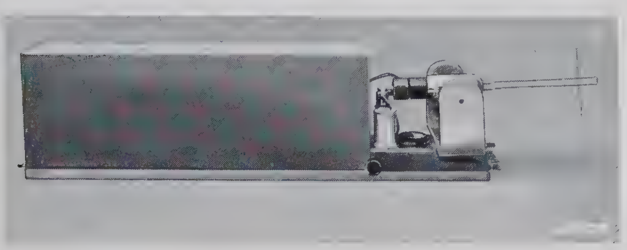


Fig. 7. Photograph of the transmitter.

The receivers

As in the case of the receivers used in the link with Tilburg which was maintained on a wave length of 125 cm, here also use is made of the superheterodyne principle.

In order to transmit with the same bandwidth as in the receivers for 1 m waves. the decision was made to try to keep the wave length of the transmitter and of the oscillator in the receiver sufficiently constant. One can then go to still shorter waves without encountering the practical impossibility of constructing a suitable intermediate frequency amplifier.

One may use an oscillator which generates either practically the same wave length as that which is to be received — namely, one which differs from it by 7.5 Mc/s, that is, the intermediate frequency which was also used in the receivers of the Eindhoven—Tilburg link — or one which generates a wave which is an integral number of times longer, and then make use of one of its harmonics. For the first method Barkhausen and possibly Pierret valves, as well as magnetrons, are available. For the second method Barkhausen or Pierret valves or triode generators may be used.

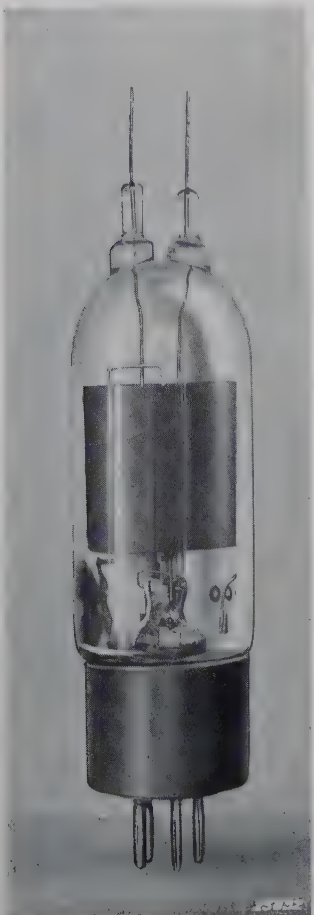


Fig. 8. Photograph of the magnetron used.

Fig. 9. Photograph of the parabolic reflector on the tower of the lamp factory in Eindhoven.

For generating Barkhausen or Pierret oscillations a triode with a tungsten filament, a cylindrical grid and a cylindrical plate is usually used. The grid is made positive with respect to the cathode, the "anode" slightly negative. A Lecher system,

consisting of two parallel wires over which a plate, the bridge *B*, can be moved, is connected to grid and anode (*fig. 10*). With the proper distance

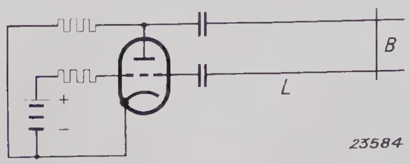


Fig. 10. Diagram of a Barkhausen valve with Lecher system.

between bridge and valve, oscillations are found to be generated whose wave length is dependent upon the anode voltage and also upon the position of the bridge.

In explanation it is usually assumed that the electrons carry out an oscillating motion around the grid which, being positive, attracts the electrons. A portion of them will shoot through the mesh of the grid instead of landing upon it, they will turn round in front of the negative "anode", shoot through the grid meshes again, turn round once more in front of the cathode, and so on. If all the electrons go through this process independently of each other, no alternating voltage will appear between the electrodes. Upon closer consideration however there seems to be a certain reciprocal action between the potentials of the electrodes and the motion of the electrons, and, as a matter of fact, between the electrons themselves. This reciprocal action causes the disordered motion to become ordered.

One may now conduct the oscillation picked up by the aerial to the Barkhausen valve. Because of non-linearity a certain degree of mixing will occur and the beat frequency between the Barkhausen oscillation and the oscillation picked up may be conducted to the intermediate-frequency amplifier.

The Pierret valve acts on the same principle as the Barkhausen valve, but there is no Lecher system between grid and anode for tuning. The grid itself (*fig. 11*), constructed in the form of a spiral without a supporting rod, is tuned in the Pierret valve.

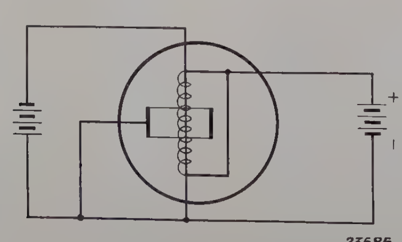


Fig. 11. Diagram of a Pierret valve.

It was found possible to construct sufficiently sensitive receivers in this way, but the control was less simple than that of triode generators, while there were no suitable indirectly heated valves available, and therefore alternating current supply could not be employed.

Further, there is the disadvantage that the frequency depends very much upon the grid voltage so that rigorous stabilization is necessary.

Later we chose the second method; the triode generator working on a wave several times longer than the wave to be received. The generator can be tuned to waves between 110 and 130 cm. The tuning is done by rotating a condenser. This oscillation of somewhat more than 1 m wave length is conducted to a diode together with the oscillation received. An acorn diode may be used here and the diode serves as a mixing valve. The circuit is shown in *fig. 12*. The coupling coil *L* is permanently tuned,

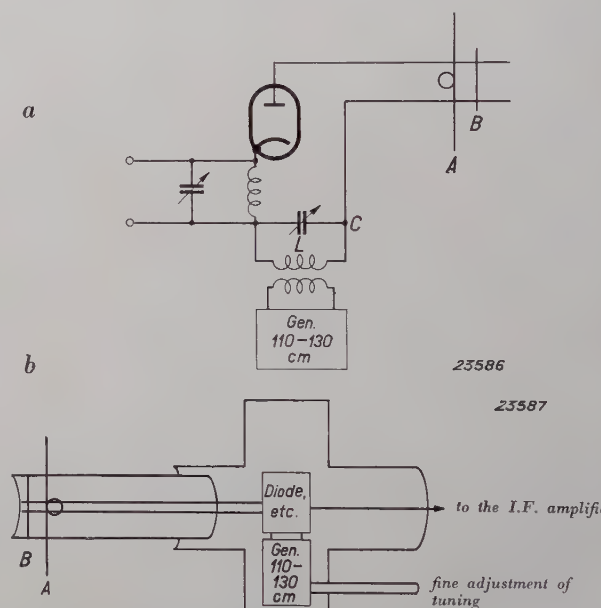


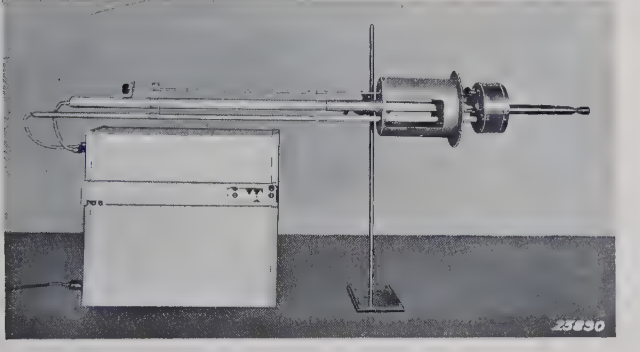
Fig. 12. *a*) Circuit, *b*) diagrammatic representation and construction scheme of the diode mixing stage.

for instance, to 120 cm. This tuning is so flat that no purpose is served by additional adjustment when the generator is turned. The wave to be received reaches the diode through the Lecher system *BC* which is tuned by shifting the bridge *B*. The aerial *A* is coupled inductively with the Lecher system. The position of the bridge must be correct within several millimetres for adequate sensitivity, fine adjustment being unnecessary. Since the Lecher system is connected directly to the intermediate frequency amplifier *via* coil *L* everything must be adequately screened. If the screening is inadequate, disturbing signals from transmitters working on a wave length of about 40 m penetrate to the receiver.

The middle of the loop of the aerial must also be connected to the screening arrangement.

In practice screening is obtained in the manner shown in *fig. 13.* The generator and the diode are mounted in a brass box provided with a tube 2 cm in diameter and 15 cm in length. A second tube slides inside the first. Within the second tube the insulated bridge is introduced; the Lecher wires run through the two tubes and pass through holes in the bridge. The aerial is attached at its middle point to the narrower tube and sticks out at both ends through large openings. The tube extends somewhat beyond the bridge in order to screen it and the remaining

a



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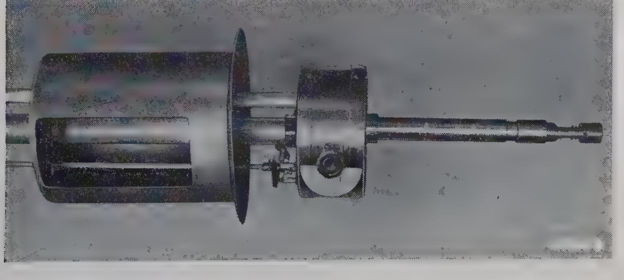


Fig. 13. *a.* represents the mixing stage, intermediate-frequency amplifier and low-frequency amplifier, *b.* the mixing stage separately on a larger scale.

part of the Lecher system. The intermediate frequency oscillation excited in the diode is conducted to the intermediate-frequency amplifier by a wire stretched in a tube fastened to the back of the box containing the generator and diode. This box is then fixed in the paraboloid or just behind it, depending upon the focal distance. The paraboloid is set up outdoors, outside a window of the water tower in our case, the intermediate-frequency amplifier, etc. are inside.

The fine adjustment of the tuning is carried out by turning a fine adjustment condenser, which is connected in parallel with the main condenser. For this purpose another rotating rod is introduced along the tube which leads in the intermediate-frequency voltage.

The voltage available at the input side of the intermediate-frequency amplifier is of the same order of magnitude as for the wave of 125 cm. Good telephone communication is possible with a

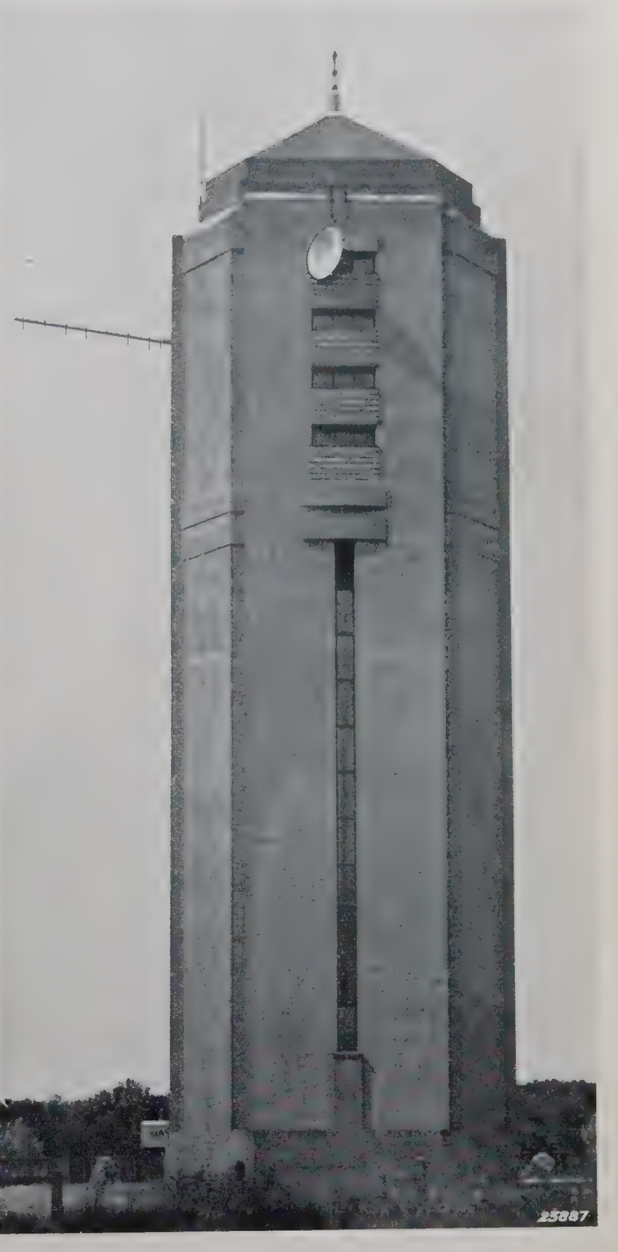


Fig. 14. Photograph of the tower in Nimeguen with the aerial system.

reflector at the receiving end having a diameter of about 1 m; for telegraphy a receiver without a reflector is sufficient. In both cases the reflector had a diameter of about 3 m at the transmitting end.

For use with large paraboloids with a focal distance of about 1 m, a long narrow receiver

was developed, in which the intermediate-frequency amplifier with the second detector and the low-frequency amplifier were mounted end to end, and the whole combined with the mixing stage and the feeder to give a unit which was set up along the axis of the paraboloid, so that as little shadow as possible was caused.

Fig. 15. Photograph of the long receiver in the paraboloid.

In *fig. 14* may be seen a picture of the long receiver and in *fig. 15* a photograph of aerial system used at the receiving end.

JOINTS BETWEEN METAL AND GLASS

by H. J. MEERKAMP VAN EMBDEN.

Summary. A survey is given of metal-glass joints and the demands made upon them in practice. The application of chrome iron to glass seals (particularly in gas discharge tubes) is discussed in some detail.

Introduction

Since Plücker and Geissler carried out their experiments with the forerunners of the modern neon tubes, gas discharge tubes have passed through a vast development, and are not only used for illumination but are finding a continually wider application in the field of radio and heavy current technique. Although originally the main object in using Geissler tubes was the study of interesting phenomena, in connection with technical applications it is now often important to be able to dissipate as great an electrical power as possible within a tube of given dimensions. This power, as in the case of practically all electrical machines, is limited by the heating permissible in relation to the construction and kind of material. Examples of heavily loaded discharge tubes have been described repeatedly in this periodical, some of these are the metal rectifier with mercury cathode [1]), the high pressure mercury lamp [2]), the water-cooled transmitter valves [3]), etc.

The choice of material for heavily loaded tubes

The endeavour to attain maximum power in the tube leads to new aspects in the choice of material.

The wall of a discharge tube must be competely impervious and the current leads must pass through this wall without the possibility of gas leakage in either direction.

At the same time the wall must be of material suitable to insulate the electrodes from each other. But in addition to this the wall fulfills still another function: if the tube is used for illumination purposes, it must transmit the radiation, while it must give up to its surroundings by conduction and radiation the energy freed as heat in the tube. Because of this the use of glass-like substances for the walls of the tube is indicated.

In the technical development of discharge tubes, as is clear from the above, limitations are encountered especially with regard to the last point. Upon increasing the power the energy dissipated as heat increases also and the wall becomes steadily hotter.

When glass apparatus is used the danger of softening or cracking of the glass with great heat is considerable, and if an attempt is made to

1) A new metal valve with a mercury cathode, Philips Techn. Rev. 1, 65, (1936).
2) The mercury lamp HP 300, Philips Techn. Rev. 1, 129 (1936).
3) The development and manufacture of the modern transmitter valves, Philips Techn. Rev. 2, 122, (1937).

decrease the amount of energy given off per unit of surface by making the tubes larger, the limit of the technically possible is soon reached, since the implosion of large evacuated containers is very dangerous.

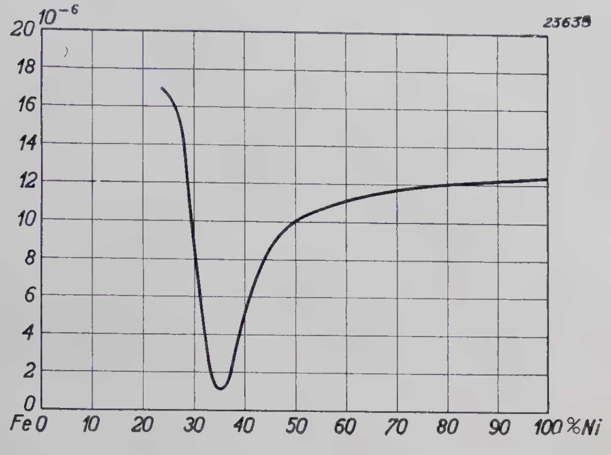


Fig. 1. Coefficient of expansion of nickel iron at 20° C as a function of the composition. With about 36 % Ni (invar) the coefficient of expansion has a sharp minimum. A coefficient of 100×10^{-7}/°C, thus equal to that of ordinary glass, is reached with about 50 % Ni. Int. Crit. Tables **2**, 465, 1927.

It is obvious that a better material must be sought for heavily loaded tubes. For high pressure mercury lamps the use of quartz, for example, which softens only at higher temperatures than glass, is an important step. In general, however, glass seems to be an outstandingly suitable material, which should only be avoided at those points where the greatest heating effect occurs. If, for instance, one could substitute a metal for the glass at the points of greatest heat development, the danger of cracking and breaking would be avoided, while the removal of heat could be made much more rapid by the use of a water jacket. Moreover the

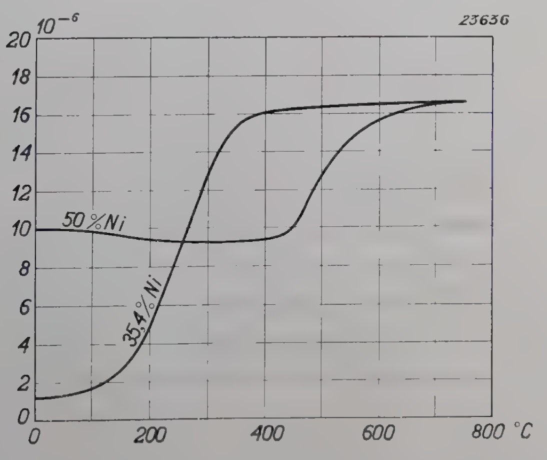


Fig. 2. Coefficient of expansion of nickel iron as a function of the temperature. a) 36 % Ni. The coefficient of expansion remains very low up to 300 °C. b) 50 % Ni. The coefficient of expansion is uniform up to 500 °C. Int. Crit. Tables **2**, 465, 1927.

accuracy with which metal can be worked is much greater than can be obtained with glass, so that the construction and installation of a partly metal tube is much simpler. The sealing of glass to a metal is not so simple however. Due to the difference in coefficients of expansion the glass usually breaks upon cooling when it is fused to a metal.

In order to prevent this there are two possibilities:

1) make the metal so thin, that upon cooling it may be plastically deformed without causing the glass to break,
2) find a metal whose expansion corresponds with that of the glass [4]).

Both methods are employed; for the first copper (linear expansion coëfficient between 0 and 300 °C, average 168×10^{-7}/° C) is usually used as the metal. It must be very thin (about 0.1 mm) in order to be welded to glass. The procedure is, however, quite difficult and expensive, due to the tendency of the copper to be oxidized, while great strength cannot be expected of the thin material near the weld.

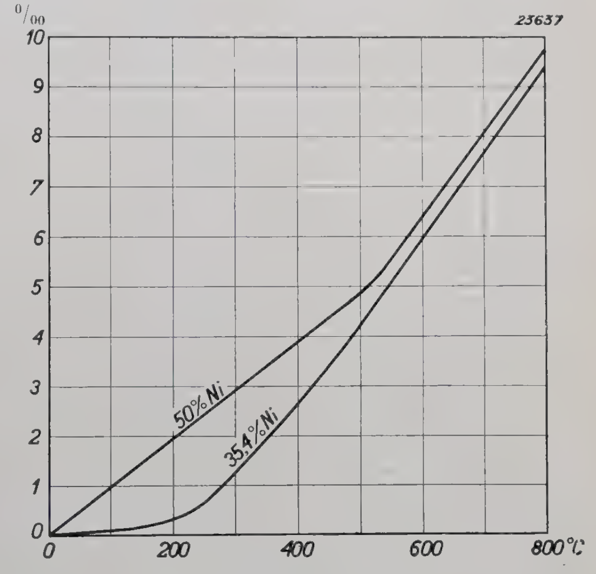


Fig. 3. Change in length as a function of the temperature. a) with 36 % Ni. b) with 50 % Ni. Int. Crit. Tables **2**, 465, 1927.

For the second method, the use of a metal adapted to the expansion of glass, we shall first discuss the requirements which the metal must satisfy. They are the following:

1) Uniform expansion throughout a long temperature range, from room temperature to above the softening point of the glass.

[4]) This does not necessarily mean that the coefficients of expansion must be exactly the same. Conversely, with similar coefficients of expansion, differences in expansion may occur, because of the fact that the metal and the glass cool off at different rates. In this connection it is desirable that the metal does not have too great a heat conduction.

2) The metal must be sufficiently stable during the sealing-in.
3) The adhesion to the glass must be good.

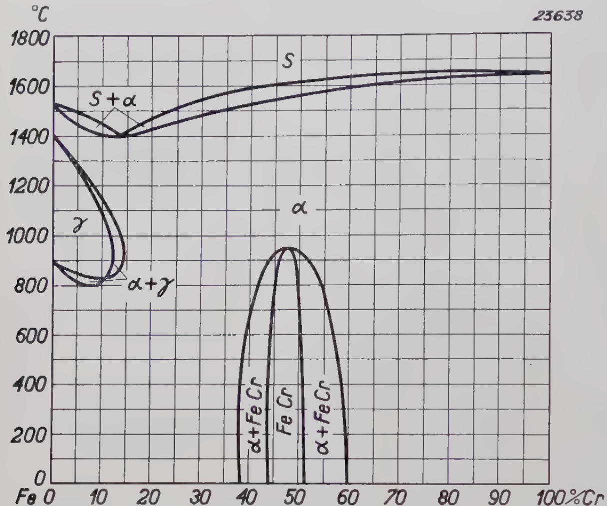


Fig. 4. The iron-chromium diagram. Taken from: Ed. Houdremont, Einführung in die Sonderstahlkunde, Springer 1935, p. 182.

4) The amount of gas given off by the metal must be small.
5) The price must be reasonable.

The significance of these requirements will be briefly explained in the following.

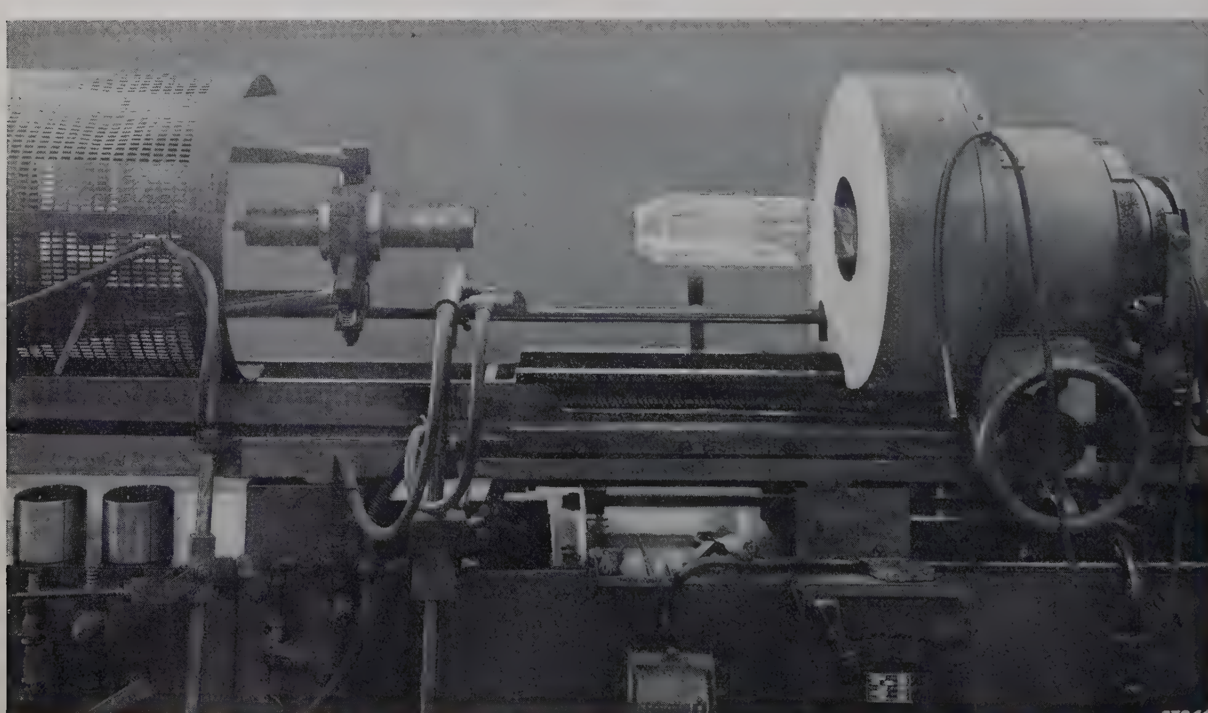


Fig. 6. Chrome iron tube with glass bulb (for transmitting valve) on the sealing-in machine.

1) The expansion of glass is uniform from room temperature to the softening point, but varies considerably for different kinds of glass. Consequently a metal which is suitable for sealing in to normal calcium glass (coefficient of expansion about $100 \times 10^{-7}/°$ C), is not suitable for sealing

Fig. 5. Example illustrating the possibility of making thick chrome iron-glass joints.

into hard glass with a coefficient of expansion of 40 to $50 \times 10^{-7}/°$ C. The metal to be sealed in must possess uniformity of expansion over a wide range, from cold to the softening point.

If allotropic transitions occur in a metal upon passing certain temperatures, for example a transition from α to β-structure, the transitions are usually accompanied by volume changes. Stresses in the metal occur which may cause cracking of the glass. It is therefore necessary to choose a

metal or an alloy which exhibits no allotropic transitions in the temperature range in which the glass is hard.

2) The sealing-in to the glass takes place at high temperatures at which glass flows; at these temperatures the metal must not yet be soft and must not burn.

3) The seal may be sufficient in some cases due to adhesion alone. The classic example of this is the glass-platinum seal. The metal remains quite bright in welding and provides an excellent seal. In the case of most metals and alloys, however,

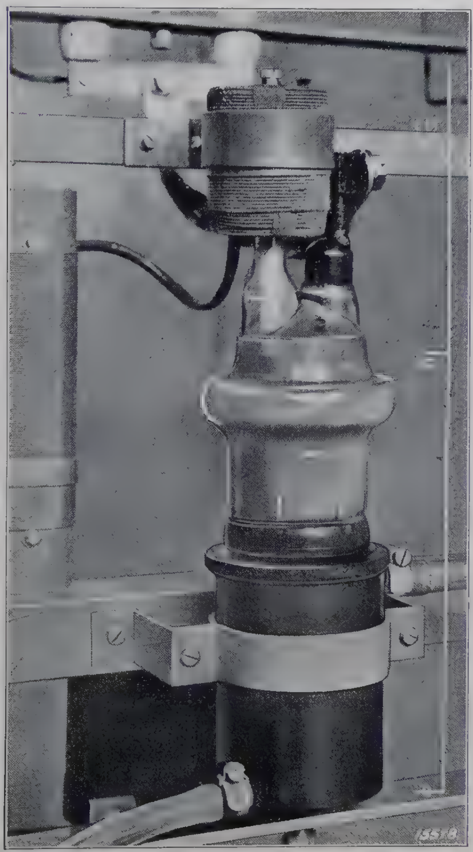


Fig. 7. A water-cooled metal valve with a mercury cathode, described in detail in Philips Techn. Rev. 1, 65 (1936). Average current strength 75 A, peak current 500 A. The chrome iron cylinder is water-cooled. It contains a pool of mercury and serves as cathode. The upper half of glass is necessary for insulation of the auxiliary anode (upper left) and the main anode (upper right) which is introduced by means of a chrome iron cap.

this is not the case and the adhesion between metal and glass is not sufficient, while at the same time the metal becomes covered with an oxide layer upon heating. This film may in some cases serve to promote a good seal when it functions as an intermediate layer between glass and metal. On one side the film is firmly bound to the metal, on the other it is to some extent dissolved in the glass forming a silicate and produces a gradual transition at this point. If, however, the oxide layer is thick and porous or has the tendency to form loose flakes, it

Fig. 8. The rectifier valve DCG 10/15, example of a more complicated construction of glass and chrome iron. Lower bulb: cathode space, upper bulb: anode space. The third bulb serves as a condensation chamber for the mercury evaporating in the lower bulb. The mercury pressure near the anode is thus kept low (little back ignition) with a high mercury pressure in the neighbourhood of the cathode (low cathode drop). The chrome iron tubes serve as auxiliary electrodes. They must be at a positive potential to ensure ignition. At the same time there is therefore the possibility of using the rectifier as a relay valve.

is obvious that there can be no question of a gas-tight seal.

4) During the sealing, and afterwards too, the metal should contain no gasses in the adsorbed

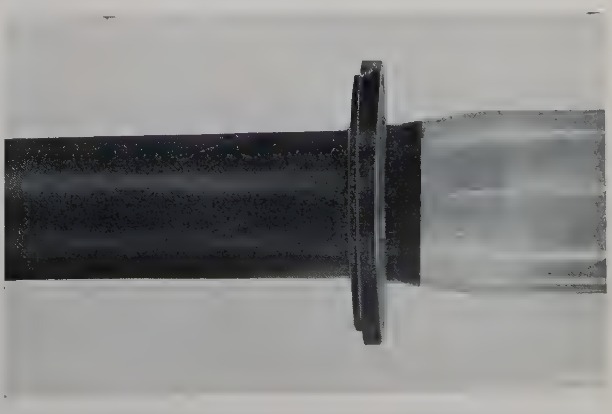


Fig. 9. Anode of a metal transmitting valve with chrome iron-glass seal.

or dissolved state, which could be freed during working. This would prevent a perfect seal. At the interface between glass and metal gas bubbles would occur which could cause leakage.

Also after the seal is finished no more gas may escape from the metal, since it would spoil the vacuum or the gas atmosphere in the tube.

5) The high costs in many cases prevent the use of a noble metal such as platinum.

Let us now list the metals which may be considered suitable for sealing to glass. For ordinary glass with a coefficient of expansion of 85 to 100 $\times$ 10^{-7}/° C we find the following possibilities:

platinum
nickel iron
chrome iron

For hard glass with a lower coefficient of expansion there are other suitable metals and alloys which correspond in expansion with hard glass. A discussion of these would lead us too far afield. Use is usually made of ternary iron-nickel-cobalt alloys and also pure tungsten and molybdenum.

Fig. 10. The heavy anode of a "Metalix" X-Ray tube is sealed to the glass with a chrome iron ring.

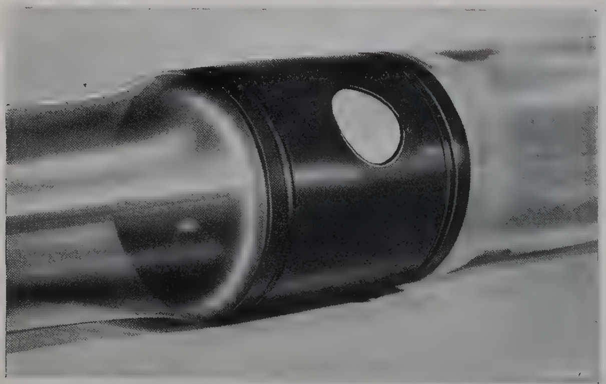


Fig. 11. The middle section of a "Metalix" X-Ray tube is made of chrome iron for screening- off undesired radiation. The X-rays are emitted exclusively through the glass window.

It has long been known of platinum, with a linear coefficient of expansion of 90 $\times$ 10^{-7}, that it gives vacuum-tight seals, and indeed the first electric lamps had platinum leads. The price is however so high that attempts were immediately made to find cheaper alloys, and at present the platinum lead is of interest only in the laboratory because of the fact that the sealing-in of such leads is so simple, the ends of the wires are always bright and ductile and the metal is so extraordinarily stable chemically.

Of the nickel-iron alloys invar, with about 36 per cent of nickel, is known for its very slight coefficient of expansion. *Figs. 1* and *2* give the coefficients of expansion of Fe-Ni alloys as a function of the composition and of the temperature. If we heat such alloys we see that the coefficient of expansion between room temperature and 150° C is practically equal to zero, but that above that temperature (*fig. 3*) we obtain a horizontal line up to 200 ° which turns sharply upward at 200 °.

If we now add more nickel to the alloy we find that the horizontal line begins to slope upward and the point where the slope suddenly changes is displaced to higher temperatures. An alloy with about 50 per cent of nickel between room temperature and 500 ° has a coefficient of expansion equal to that of glass, above the latter temperature it is somewhat higher. This is however not dangerous, since at those higher temperatures the glass is soft and therefore will not crack.

With regard to expansion therefore the latter alloy is a suitable one, and is in fact very often used as sealing-in wire for lamps but it has however several disadvantages particularly with regard to adhesion. Upon sealing it in, the wire is strongly oxidized and the oxide has a great tendency to flake off, while in addition it is very

difficult to make this material gasfree. Nickel absorbs all kinds of gasses very easily (its use as a catalyst is an example of the application of this property), and these gases are easily given off again. That is the reason why the sealing-in wires are often covered with a thin layer of copper

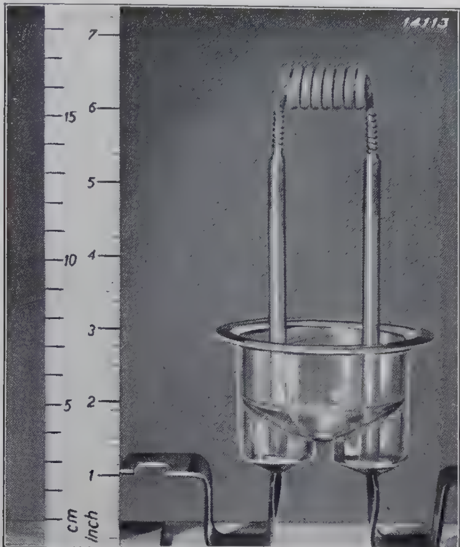


Fig. 12. Simple lead-in in a rectifier, consisting of a chrome iron plate with terminals soldered on to both sides.

(borated copper), since the adhesion of glass to copper by means of the film of copper oxide is very firm. Since copper has a much higher coefficient of expansion, the copper coating must be very thin so that it may be plastically deformed without cracking the glass. For larger seals nickel iron is out of the question.

On the other hand for large seals chrome iron has found extended application. Before we consider its application we shall first study the iron-chromium system. The diagram of the iron-chromium system is given in *fig. 4*. When pure iron is heated, it passes over into another modification, γ-iron, at 906 °C. γ-iron has a different atomic arrangement than the α-iron [5]) stable below this temperature.

Upon further heating γ-iron passes over at 1401° C into α-iron again which is identical with the α-iron stable below 906 °C. α-iron melts at 1528 °C. Upon cooling the transitions occur at the same points, solid at 1528°, α-iron to 1401°, γ-iron to 906° and α-iron lower. If we add chromium as alloying element we find that the two transition points approach each other with increasing chromium content; with about 15 per cent of chromium they coincide. An alloy with more than 15 per cent chromium and the rest iron consists therefore only of α-crystals between room temperature and the melting point.

That means that the expansion due to change of temperature proceeds quite uniformly without the transitions $\alpha \rightarrow \gamma$ which are accompanied by large changes in volume. Moreover the coefficient of expansion is 100×10^{-7} and corresponds therefore very well with that of glass.

Technical procedure in sealing

The alloy is melted in an electric furnace for which the electric arc furnace as well as the more modern high frequency furnace may be used. It is then poured into casting moulds and forms ingots. The ingots are now rolled into rods or sheets and the pieces intended for sealing in to glass are made from these by turning, drawing, etc. Thin sheet can very well be drawn, care must be taken however in rolling that the material is not given an anisotropic texture by cold working, since this would give bad results in the drawing [6]).

Chrome iron is fairly resistant to air. This stability is ascribed to the formation of an extremely thin film of oxide which entirely covers the surface and protects it from further attack by the atmosphere. Various chromium alloys are on the market as stainless steel. In our case the oxide film forms a

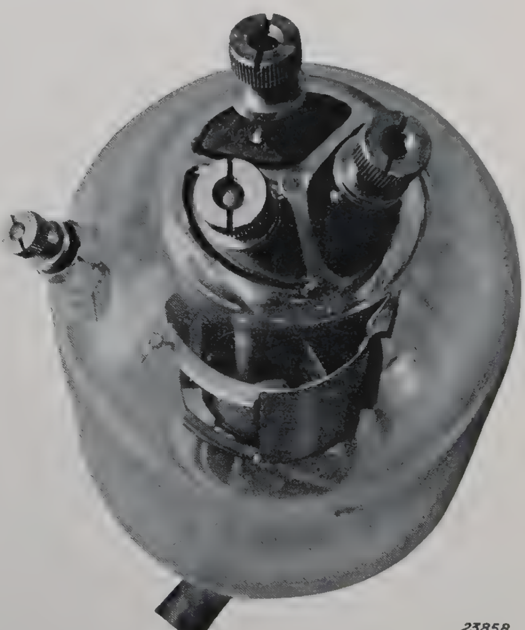


Fig. 13. Three electrodes of a rectifier valve are led in by means of sector-shaped chrome iron plates. The three plates are first welded together with a glass edge to give a circular plate and then sealed on to the circular opening of the rectifier bulb.

[5]) The atomic arrangement for α and γ-structure is shown in Philips Techn. Rev. **2**, 253, (1937).

[6]) See Philips Techn. Rev. **2**, 156, (1937). for the drawing of chrome iron cups (Example **23** for X-Ray testing of materials).

connecting substance between glass and metal, and it is obtained in the proper thickness for good adhesion by heating the chrome iron with the flame directly before the sealing into the glass.

Fig. 5 shows that even thick pieces of glass and chrome iron may adhere very well to each other. The fact that such a sealing-in may be carried out with chrome iron is due in part to the fact that the heat conduction of this alloy is very small.

For sealing large pieces a special lathe has been made (*fig. 7*) with two chucks opposite each other. In one chuck the chrome iron in tube form is held, in the other the glass part. While

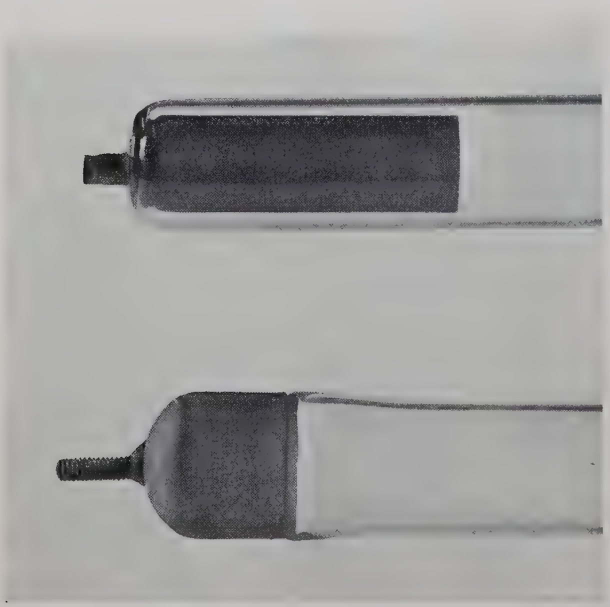


Fig. 14. The use of chrome iron anodes in neon tubes leads to a very simple construction.

both are turning the edge of the chrome iron is first heated and oxidized, after which a thin layer of glass is deposited by hand upon the hot edge by applying a thin glass rod to it. After that the edge of the piece of glass to be welded is heated and the two chucks are brought together, still rotating. The glass seal is then obtained as an ordinary glass butt weld by fusing. The edge of the chrome iron tube in the above described process need not be sharp or even thin, a fact which is favourable to the strength of the glass-metal seal. In this respect chrome iron is distinct from all other ordinary sealing-in alloys which can only be sealed into glass in the form of thin, sharply beveled edges. *Figs. 7* and *8* show two important examples of the glass-chrome iron butt weld in the construction of large rectifiers. In the case of the very large water-cooled transmitting valves the sealing ring on which the glass is fused is made of chrome iron (*fig. 9*). This ring is soldered to a copper tube which is water-cooled. The heat conduction of copper is much better than that of chrome iron, so that more heat can be conducted away in this manner. The same principle is used in the case of the anodes of X-ray tubes (*fig. 10*), where a very high heat conduction is required. The anode therefore consists of a block of copper which is fused to one edge of a chrome iron ring, the other end of which is then joined to the glass.

The middle sections of the Philips "Metalix" X-ray tubes are also made of chrome iron (*fig. 11*) and a window for transmitting the beam of rays is sealed in. This would not be so simple with metals other than chrome iron. The tube is mounted in the apparatus by this metal middle section.

If it is desired to make current lead wires, for very heavy currents one may take a chrome iron cap with a turned edge on which a glass tube can be sealed in the manner described. The cap is then provided with a lead wire in the middle of the inner side which is soldered to the cap, and with a second wire on the outer side. Afterwards the whole can be sealed into the glass tube.

For smaller current strengths, for example in the rectifier given in *fig. 12*, a chrome iron plate is sufficient, which is provided on both sides with glass. It is then sealed into the glass tube. Several such plates may be "joined to a foot", which is sealed into the rectifier valve as a whole after assembly. *Fig. 13* gives an example of this.

Another example may be seen in the electrodes of a neon tube (*fig. 14*) in which a light cup of chrome iron which serves as electrode is sealed at its edge directly to the end of the glass tube so that the external current supply can take place directly through the base.

For additional technical applications reference is made to the possibility of introducing glass windows into pressure or vacuum boilers, and to the use of glass connecting pieces on metal reaction chambers, while the special application for telescope mirrors [7]) has already been mentioned.

[7]) Telescope mirrors, Philips Tech. Rev. 1, 358 (1936).

Illumination of the Eiffel-tower at the Paris World Exhibition (1937). The greater part of the electrical plant has been equipped by, or with material of, S. A. Philips - Paris.

THE EXAMINATION OF THE MACRO-STRUCTURE OF RAW MATERIALS AND PRODUCTS WITH THE HELP OF X-RAYS I

by J. E. DE GRAAF.

Summary. This article explains the essentials of the testing of raw materials and products by means of X-rays according to the absorption method. In a number of short articles the practical applications and the results obtained by this method will be studied in some detail.

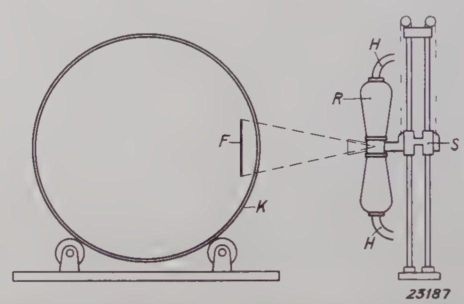
Introduction

In the application of X-rays to the examination of technical materials two large fields must be distinguished:

1) The investigation of the structure and texture of crystals (micro-structure) by means of the interference of the X-rays on the surface of the crystals [1]). The X-rays which produce the photograph are not the direct rays from the X-ray tube, but deflected rays. X-rays of rather long wave lengths are used (1 to 2 Å; 1 Ångström = 10^{-8} cm), which are unable to penetrate deeply into the object being examined. The micro-structure at the surface of the object is therefore examined.
2) The detection of cavities, cracks etc., in short, of faults which could be observed with the naked eye if the article were cut through in the proper place (macro-structure). The direct rays, which in this case are of very short wave lengths (for instance 0.1 Å) first pass through the article to be examined (*fig. 1*), in which they are absorbed to a greater or smaller degree, then they blacken a film to a correspondingly smaller or greater degree.

For homogeneous material the absorption of X-rays is the same throughout the mass; because of "inhomogeneities", such, for example, as enclosures of slag, the absorption may vary locally. On the film, which is chosen instead of a plate because of its durability, and which is provided with a sensitive emulsion on both sides, a picture of the object appears in which macro-faults may be seen more or less clearly. In this manner therefore the entire volume of the object is investigated, and not exclusively the surface layer.

Considering the fact that the blackening of the X-ray film depends upon the absorption of the X-rays in the film, and that this absorption is small, the time of exposure necessary to obtain a photograph with sufficient blackening becomes very long. The photographic action is therefore almost always reinforced by placing an intensifying



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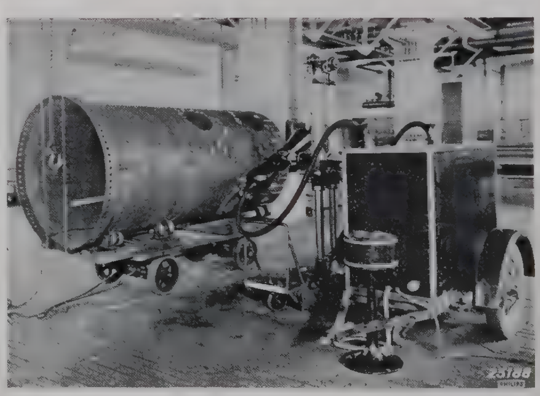

b

Fig. 1. *a*) Diagram of the X-ray testing of a boiler by the absorption method. *F* film, *K* boiler, *H* high voltage cable, *R* X-ray tube and *S* stand. *b*) Photograph of this test.

screen directly against the film. This screen fluoresces under the influence of the X-rays. It is usually covered with a layer of calcium tungstate. The fluorescent light of this layer contributes appreciably to the blackening of the film; the intensity of the light is proportional to the amount of incident radiation. The reinforcement obtained with such a screen may amount to a factor of thirty.

Influence of the thickness and nature of the material

If we first study the influence of the absorbing thickness of the material with otherwise similar conditions as regards time of exposure, distance

[1]) This was discussed in the August number of this periodical in the completed series entitled "Practical applications of the testing of materials by means of X-rays" by W. G. Burgers.

of the film from the X-ray tube, etc., we observe an absorption which increases rapidly with the thickness (*fig. 2*). It is found that in the first ap-

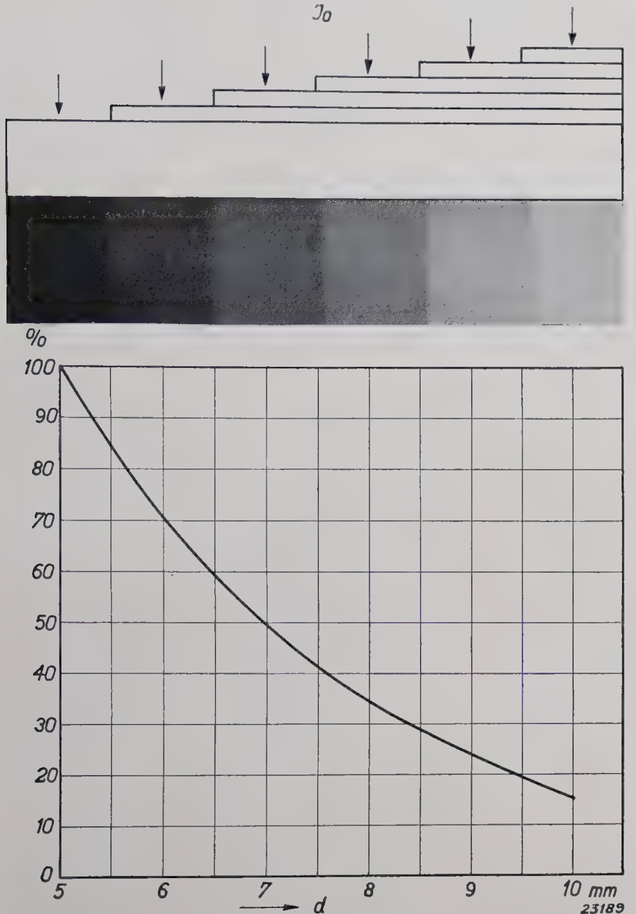

Fig. 2. Absorption of a beam of X-rays by different thicknesses of the same material. For this purpose an iron plate 5 mm thick was taken, upon which additional 1 mm layers of iron were laid until the final thickness was 10 mm.

proximation a certain thickness of material added to another layer of material always removes the same percentage of the radiation passing through the latter layer, no matter what the thickness of this layer (provided it is not too small). In reality this exponential increase of the absorption holds exactly only for monochromatic radiation, that is radiation of a single wave length. For the continuous spectrum emitted by an X-ray tube it holds however to a better approximation the thicker the layer of material through which the radiation passes, since the long waves are absorbed much more strongly than the short waves, and the radiation therefore becomes more homogeneous.

With equal thicknesses of material the nature of the material of the object examined still makes a great difference. Of the simultaneously photographed (*fig. 3*) equally thick plates of lead, tin, iron and aluminium, the aluminium plate is invisible because it has not absorbed appreciably. Behind the lead plate the film has remained practically clear which means that the lead has

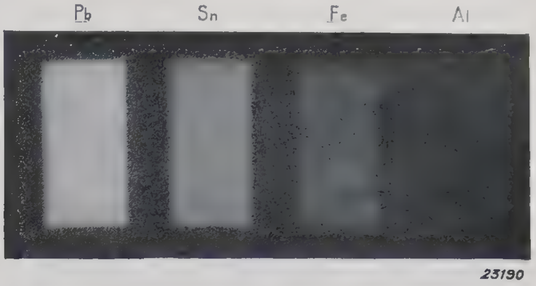

Fig. 3. Absorption of a beam of X-rays by the same thickness (0.2 mm) of different metals: lead (atomic weight 207), tin (119), iron (56) and aluminium (27) on an iron plate 10 mm thick. Exposure time 3 min., tube voltage 100 kV, current 4 mA. The aluminium because of the slightness of the contrast, is practically invisible.

absorbed nearly all the radiation. Roughly these results may be summarized in the following way: with increasing atomic weight substances absorb more strongly. This means therefore that in order to obtain the same absorption an appreciably thicker layer of aluminium is necessary than of iron. Or conversely: one can irradiate and examine appreciably greater thicknesses of aluminium than of iron under the same conditions.

Gases do not absorb appreciably even compared with aluminium. A hole filled with gas will be shown on the film in just the same way as when it was quite empty. Even when a cavity is filled with slag, this will not always be observable from the difference of blackening caused by this cavity. The greater the absorbtion of the metal itself, and the more gas bubbles the slag contains, the slighter the difference observable between a cavity filled with slag and one filled with gas. In such cases one must employ other peculiarities such as shape and position in order to be able to make any statement about the cause of the cavity.

On the other hand, greater differences in absorptive capacity, such as that between the metal connecting wires and the "Philite" in the base of the radio lamp in *fig. 4*, are clearly shown. For checking the work of assembly this fact has of course opened many possibilities of application. The photograph shows at the same time very clearly how sharply fine parts (thin wires) can be photographed with the help of X-rays.

Influence of the tube voltage

A third important factor in the detection of defects in materials, in addition to the thickness and nature of the materials, is the influence of the voltage between the anode and cathode of the

X-ray tube. The higher the voltage the shorter the waves occurring in the spectrum and the less the absorption of the radiation. Since in addition the output of the X-ray tube increases with increasing

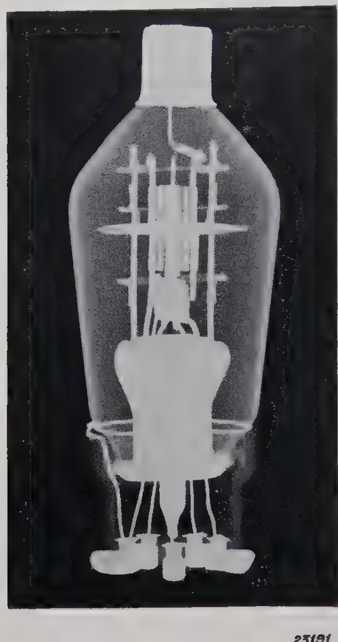

Fig. 4. X-ray photograph of a radio check of the assembly. Inside the visually non-transparent "Philite" socket may be seen the electrode leads. Inside the lamp in the stem and the pinch these wires are no longer visible. The glass of these parts contains a high proportion of lead (30 %) and the contrast effect through the fairly thick wires disappears. The assembly, however may be easily inspected.

voltage, the radiation passing through a certain thickness of material and also the blackening of the photographic plate caused thereby will increase rapidly with increasing voltage (*fig. 5*). This means again that one obtains a sufficiently blackened photograph of a definite thickness of material in a

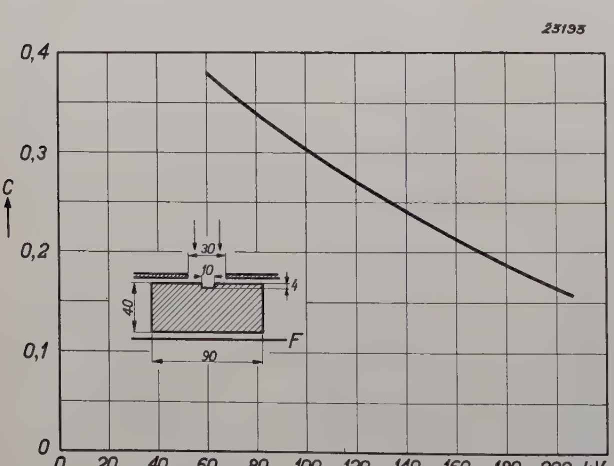

Fig. 6. Contrast C caused by a hole in a block of aluminium whose dimensions are given in mm on X-ray photographs taken at different voltages. A diaphragm of lead lies upon the aluminium in order to limit the field.

shorter time, the higher the tube voltage. It is however incorrect to conclude from this that one must therefore always use as high a voltage as possible. *Fig. 6* gives the difference in degree of blackening (contrast) caused by a hole in a block of aluminium when the block is photographed at different voltages in such a way that the main blackening remains the same. Between the tube voltages of 75 and 200 k.V. the contrast is found to decrease by about a factor of two, due to the decrease of absorption with increasing tube voltage which results in the fact that a given difference in thick-

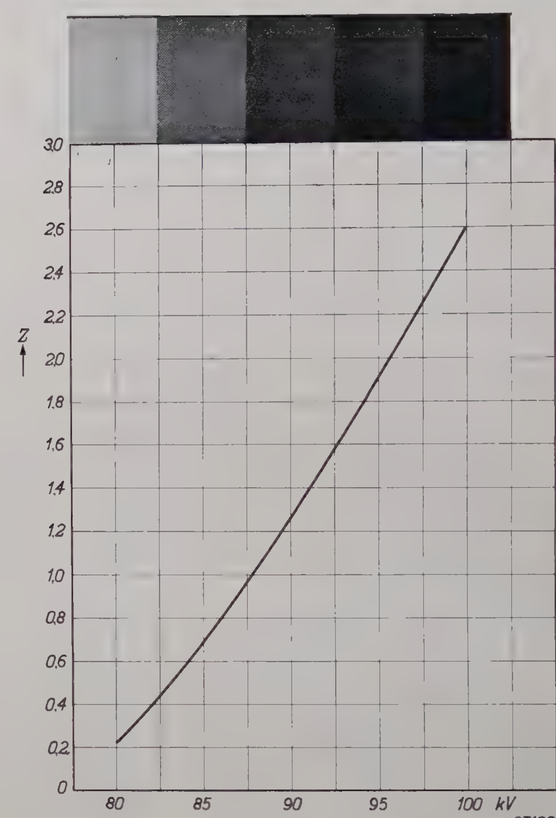

Fig. 5. Blackening Z due to X-ray beams with different tube voltages V with a current strength of 4 mA and an exposure time of 75 sec. behind 5 mm of iron. In the graph Z is shown its relation to V.

ness gives less contrast at higher voltage. This decrease in contrast may seem small, but it will be found that there is always a rather strong influence by the voltage on the visibility of fine details, since it is just in the appreciation of fine details which lie at the limit of visibility that a slight change of contrast makes a great difference. This dependence makes it important to establish the limit of visibility on each photograph by indication, for example, of the smallest difference in thickness distinguishable. For this purpose one may employ a frame with wires of different thicknesses made of the material of the object being examined. This frame

is photographed at the same time as the object being placed upon the latter. The thickness of the thinnest wire just discernable must satisfy certain requirements: with objects up to 50 mm in thickness it must be at the most $1^1/_2$ per cent of this thickness. At the same time this affords a check on the dark room technique, since, when insufficient care is taken in developing, as a matter of fact well-taken photographs may be so badly treated that they give pictures with little contrast.

From the foregoing it will be obvious that every X-ray photograph for the testing of material is a compromise between the desire for a short time of exposure and the desire for good detail. As a rule exposure times of some minutes are chosen (of such length that the exposure times are short with respect to the time necessary for changing the films and adjusting the X-ray tube): the voltage necessary with a certain thickness of material for a photograph with an exposure time so chosen is taken from exposure graphs, such as that given in *fig.* 7 for iron.

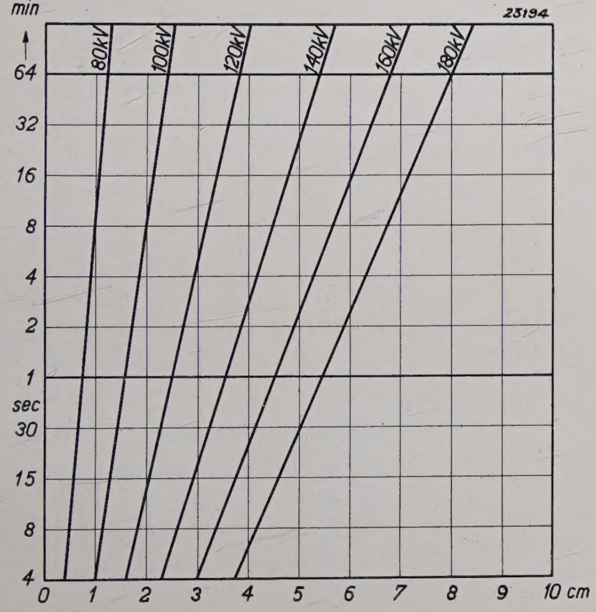

Fig. 7. Exposure graph for iron with intensifying screen and Agfa Spezialfilm. The thickness of the iron is plotted horizontally, the time of exposure vertically. The curves give the relation between the two at a constant blackening $Z = 0.5$ with the tube voltage as parameter, current 4 mA; distance between focus and film 40 cm, field 4×4 cm^2.

Visual observation

Besides the photographic method it is possible to apply direct visual observation with the aid of fluorescent screens. If such a screen is placed where the film would otherwise be, the fluorescent image can be observed on the screen with the eye. The radiation passed through the object must however not be too weak, that is to say, the objects must not be too heavy or too thick. In the case of iron the thickness for visual investigation must not be greater than about 20 mm. Since the contrasts are slighter in the fluorescence test than in the photographic method, and since there is no record made, the fluorescence method, although cheaper and quicker, is seldom employed for important tests. For the testing of technically less important parts visual observation is more desirable because the parts are, as a rule, much cheaper than the important ones, and thus require a cheaper method of testing.

Importance of the absorption method

When all the differences of density and thickness of the object to be examined are more or less clearly delineated on an X-ray photograph, the photograph can be used to detect undesired differences, that is, defects. The value of this method of detection by X-rays is twofold: firstly the photograph (in contrast to a cross section at one place) immediately gives a detailed view of the faults and of their relation to each other, and secondly the object is not sacrificed to the examination, which means that all objects whose importance makes it desirable may be tested. The first point is of significance not only in the development of new methods of manufacture in foundries and the like, where it is of immediate importance to be able to diagnose the cause of the fault, but also in testing production since from the cause of the fault, when once known, qualitative conclusions may very often be drawn as regards a decrease in strength due to factors not immediately observable such as changed structures. Thus the diagnosis of welding faults is of primary importance in the testing of welded boilers and other structures.

In a series of short articles we intend to discuss in more detail various examples of the application of irradiation by X-rays for the purpose of detecting defects in materials.

REVIEW OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1199*: R. Houwink and K. H. Klaassens: Die Viskositäts-Konzentrationsabhängigkeit in konzentrierter Lösung und ihre energetische Deutung, III (Koll. Zeit., **79**, 138 - 148, May, 1937).

The article by the above authors summarised in Abstract No. 1130 led to a closer collaboration with H. L. Bredée and J. de Booys in investigating the nature of the relationship between the viscosity of colloidal solutions, their concentration and the size of the particles concerned.

In conjunction with two articles by Bredée and de Booys (Koll. Zeit., **79**, 31 and 43, 1937), an empirical formula is given which satisfactorily expresses the viscosity of very different substances over a wide range of concentrations and which at low concentrations passes over into the Einstein formula.

The increase in the viscosity due to dispersed particles may be resolved into two components which are determined by the shape of the particles and by the space occupied by them respectively. It is found that elongated particles cause a relatively smaller increase in the viscosity of concentrated solutions than shorter, and particularly spherical, ones. This can be shown to be due to the differences in the change in energy transmission with the concentration between elongated and round particles.

No. 1200: J. A. M. van Liempt and J. A. de Vriend: Über das Verbrennungslicht von Al-Zn- und Al-Cd-Legierungen (Rec. Trav. chim. Pays-Bas, **56**, 594 - 598, May, 1937).

If zinc or cadmium is added to aluminium, its combustibility in oxygen is considerably increased. The rate of combustion and the actinic output are considerably augmented, without the colour of the light being altered to any appreciable extent.

No. 1201: J. A. M. van Liempt and J. H. M. Uden: Der photographische Nachweis von Thoriumoxyd in Glühdrähten (Rec. Trav. chim. Pays-Bas, **56**, 607 - 612, May, 1937).

The presence of thorium oxide in tungsten incandescent filaments can be detected by means of the blackening produced on a photographic plate by the radio-active radiation from the thorium. Schumann plates are the most suitable for this purpose, next in suitability are the most sensitive ordinary plates. The sensitivity of this method increases with the thickness of the filament, the time of exposure and the atmospheric humidity. Drawn filaments give a deeper blackening than crystalline or single-crystal wires. Pure thorium wire gives a very deep blackening.

No. 1202: F. A. Heyn: De techniek der kerntransformaties (Ingenieur, **52,** E51 - 56, May, 1937).

This paper gives a general survey of the various methods available for initiating nuclear transformations. The discussion shows how these transformations can be produced by means of alpha particles and the neutrons formed simultaneously with them, and how charged particles can be sufficiently accelerated by high voltages or by repeated passage through the same comparatively small potential difference so as to result in these transformations.

No. 1203: W. de Groot: Interpretatie van moleculaire verschijnselen door middel van potentiaal-krommen. I. Potentiaalkrommen van het tweeatomige molecuul (Ned. T. Natuurk., **4**, 109 - 119, May, 1937).

Some properties of potential curves of the type introduced by Franck (1925) are discussed in this and several subsequent articles with special reference to problems in molecular physics, including predissociation and photo-ionisation.

No. 1204: W. Elenbaas: Die Gesamtstrahlung der Quecksilberhochdruckentladung als Funktion der Leistung, des Durchmessers und des Druckes (Physica, **4**, 413 - 417, June, 1937).

For different pressures (0.1 to 25 atmos.) and with different loading L per cm of tube length (8 to 75 watts per cm), the total radiation of the high-pressure mercury discharge was measures for tube diameters d of 3.3 mm, 9.2 mm and 27 mm.

*) There is not a sufficient number of reprints available for distribution of the publications marked *). Reprints of the other publications will on request gladly be supplied by the Administratie van het Natuurkundig Laboratorium, Kastanjelaan, Eindhoven.

For power values above 20 watts per cm and pressures above 10/d atmos, the total radiation is equal to 0.72 (L - 10) watts per cm.

No. 1205: J. F. H. Custers: The ultraviolet absorption spectrum of potassium perrhenate (Physica, **4**, 426 - 429, June, 1937).

The absorption spectra of an aqueous solution of potassium perrhenate were measured for various centrations in the region between 3134 and 2210 Å. At approximately 3150 Å the absorption becomes notice- able; at 2290 Å there is a strong absorption maximum and at 2390 Å a scarcely noticeable maximum. The absorption spectra of the permanganate and the perrhenate ions are compared with each other.

No. 1206: A. A. Kruithof and F. M. Penning: Determination of the Townsend ionisation coefficient for mixtures of neon and argon (Physica, **4**, 430 - 449, June, 1937).

The ionisation coefficient α was plotted as a function of the quotient of the field intensity E in volts per cm and the pressure p_0 in mm Hg (reduced to deg. C) for pure neon and eight different mixtures of neon and argon. The results obtained are in agreement with previous estimates of the ionisation from the starting voltage of luminescent discharges. The most marked ionisation, corresponding to a doubling of the number of electrons on passing through a voltage of 18.7 volts, was found at $E/p = 3$ volts per cm and per mm Hg with neon containing 0.1 per cent argon. If the quotient E/p is made smaller, the ionisation coefficient is considerably reduced owing to the energy losses of the electrons on elastic collision with the atoms of the gas.

Since, according to earlier papers, the photoelectric current at constant field intensity increases more or less in stages, special attention was given to the exact determination of the current as a function of the distance between the electrodes.

No. 1207: A. A. Kruithof and M. J. Druyvesteyn: The Townsend ionisation coefficient α and some elementary processes in neon with small admixtures of argon (Physica, 4, 450 - 463, June, 1937).

From the Townsend ionisation coefficient, the probability χ of an excited neon atom ionising an argon atom was calculated by two different methods, viz.: a) assuming the probability that a neon atom is excited by impact of an electron, and b) taking as a basis the measurements described in No. **1026** in which the mean ionisation was measured as a function of the distance from the cathode. From the connection between χ and the percentage proportion of argon, it follows that nearly 90 per cent of the neon excitations give a metastable atom if the quotient of the field intensity in volts per cm and the pressure in mm is lower than 3.5.

No. 1208: M. J. Druyvesteyn; The mobility of electrons in neon (Physica, **4**, 464 - 466, June, 1936).

The drift velocity of electrons was calculated from the velocity distribution obtained in measurements described in Abstract No. **1207**. The calculated curves for pure neon and neon containing a small proportion of impurities are in satisfactory agreement with the values found experimentally.

No. 1209: H. Bruining and J. H. de Boer: Secondary electron emission of metals with a low work function (Physica, **4**, 473 - 477, June, 1937).

It is concluded from measurements on the secondary emission of pure metals and the effect of impurities that the more or less free electrons contribute only slightly to secondary emission under bombardment by primary electrons having energies of several hunderd volts. The facility for secondary emission may be increased by impurities, which partly bind the electrons. The relationship between secondary emission and the thickness of the deposited layer also was investigated. Emission commences with a value corresponding to that of the base metal, reaches a maximum which may be a multiple of the initial value, and then diminishes again with increasing thickness of the deposited layer to a value equivalent to that of the coating metal.